A SYNTHESIS AND SOURCING GUIDE TO OVER THE COUNTER PYROTECHNICS – 2nd EDITION

An OTC Composition Repository, Chemical Sourcing and Synthesis Guide

The following guide is an ordered collection of information regarding over the counter chemical sourcing and synthesis. The focus of this guide is directing amateur pyrotechnicians in practicing pyrotechnics without reliance on dedicated pyrotechnic supply companies. To facilitate this endeavour, the following guide also presents a new potassium-chlorate-based colour star system which uses solely OTC chemicals.

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PLEASE REPORT ALL ERRORS

BY NC ND

THIS TABLE IS HYPERLINKED FOR EASE OF NAVIGATION

Table of Contents

Over the Counter Composition Repository 1
Simple Potassium-Nitrate-Based Compositions 1
Helix Series Pyrotechnic Colour Compositions (Listed) 2
Helix Series Pyrotechnic Colour Compositions (Tabulated) 4

Chemical Sourcing and Synthesis Guide 5
Potassium Nitrate Sourcing 5
Sulphur Sourcing 6
Charcoal Sourcing 6
Hardwood Charcoal Sourcing (Horticultural) 6
Softwood Charcoal Sourcing (Lump) 6
Dextrin Production 7
Wheat Flour Sourcing 7
Aluminium Sourcing and Production 8
Spherical -200 Mesh Aluminium Sourcing 8
Flake Dark Aluminium Production 8
Sodium Bicarbonate Sourcing 9
Potassium Chlorate Production 9
MMO Sourcing 9
KCl Sourcing 10
Methodology: Filtration Setup 11
Barium Chlorate Production 11
$BaCO_3$ Sourcing 12
Methodology: Evaporation Bucket 14
Copper Oxychloride Synthesis 14
CuO Sourcing 15
KOH Sourcing 15
K_2CO_3 Sourcing 15
Simplified 100g Example Synthesis 16
Clear uPVC Cement Sourcing 17
Colophony Sourcing 18
Shellac Sourcing 19

Lactose Sourcing 19
Sodium Oxalate Synthesis 19
Simplified 100g Example Synthesis 22
Strontium Carbonate Sourcing 23
Chemical Purification of Sulphide Contaminated $SrCO_3$ 24
Simplified 100g Example Purification 26
Red Iron Oxide Sourcing 27

Appendix #1 28
Preparation Notes for the Helix Series Compositions 28
Preparation Notes: Red, Orange, Yellow and Green 28
Preparation Notes: Blue, Purple and Pink 29
Preparation Notes: Prime 30
Colour Testing of the Helix Series Compositions 30
Composition Performance Notes for the Helix Series Compositions 31
Substitutions for Helix Blue, Helix Purple and Helix Pink 32
Copper Oxide Substitution 32
Copper Oxychloride Fungicide Sourcing and Substitution 32
PVC Dry Blend Resin Powder Sourcing and Substitution 34
Alternative Blue Star Compositions for Powdered PVC 35
Recrystallisation of $KClO_3$ for Sensitive Star Compositions 36
Additional Chemical Sourcing and Synthesis Information 37
Hydrochloric Acid Sourcing 37
Boric Acid Synthesis 37

Appendix #2 39
Standard Ionic Solubility Chart 39
Pyrotechnic Chemistry Solubility Tables 39
$(NH_4)_2CO_3$ 39
$Ba(ClO_3)_2$, $BaCl_2$, H_3BO_3, $CuCl_2$, K_2CO_3, $KClO_3$, KCl *and* KOH 40
$NaCO_3$, $NaHCO_3$, $NaCl$, $NaOH$, $Na_2C_2H_2O_4$, $Na_2B_4O_7 \cdot 10H_2O$, $SrCl_2$ *and* $C_2H_2O_4 \cdot H_2O$ 41

References and Further Reading 43

Over the Counter Composition Repository

Black Powder

Potassium Nitrate (75 Parts)

Lump Charcoal (15 Parts)

Sulphur (10 Parts)

+ Dextrin (5 Parts)

Nozzleless Black Powder Rocket Fuel

Potassium Nitrate (75 Parts)

Lump Charcoal (15 Parts)

Sulphur (10 Parts)

+ 80 Mesh Charcoal (5 Parts)

Nitrate Based Slow Flash

Air-float Potassium Nitrate (50 Parts)

Dark Aluminium Powder (30 Parts)

Air-float Sulphur (20 Parts)

Flash Report Composition

Air-float Potassium Chlorate (62 Parts)

Dark Aluminium Powder (23 Parts)

Air-float Sulphur (15 Parts)

This composition is extremely dangerous. Before even considering its use, consult with an experienced pyrotechnician. If you choose not to, remember - natural selection forgets no one.

D1 Glitter †

Potassium Nitrate (53 Parts)

Horticultural Charcoal (11 Parts)

Sulphur (18 Parts)

Spherical Aluminium (7 Parts)

Sodium Bicarbonate (7 Parts)

Dextrin (5 Parts)

Chrysanthemum 6

Potassium Nitrate (55 Parts)

Horticultural Charcoal (33 Parts)

Sulphur (7 Parts)

Dextrin (5 Parts)

Bill Ofca’s Gold Spider Web

Potassium Nitrate (54 Parts)

Horticultural Charcoal (32 Parts)

Sulphur (7 Parts)

Dextrin (7 Parts)

Shimizu’s Tiger Tail

Potassium Nitrate (44 Parts)

Horticultural Charcoal (44 Parts)

Sulphur (6 Parts)

Dextrin (6 Parts)

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† If a reaction between the KNO_3 and aluminium is of concern to the reader, a boric acid synthesis has been provided in Appendix #1 on page. 37.

Chrysanthemum of Mystery

Potassium Nitrate (50 Parts)

Horticultural Charcoal (45 Parts)

Dextrin (5 Parts)

Hardt Silver Streamer/ White

Potassium Nitrate (11 Parts)

Meal Powder (56 Parts)

Sulphur (7.5 Parts)

Dark Aluminium (17 Parts)

Wheat Flour (11 Parts)

Dextrin (5 Parts)

Helix Red

Potassium Chlorate (70 Parts)

Strontium Carbonate (15 Parts)

Colophony (10 Parts)

Horticultural Charcoal (1 Part)

Dextrin (4 Parts)

Helix Orange

Potassium Chlorate (76 Parts)

Strontium Carbonate (4 Parts)

Sodium Oxalate (4 Parts)

Colophony (8 Parts)

Shellac (4 Parts)

Dextrin (4 Parts)

Helix Yellow

Potassium Chlorate (76 Parts)

Sodium Oxalate (10 Parts)

Colophony (4.5 Parts)

Shellac (4.5 Parts)

Dextrin (5 Parts)

Helix Green

Potassium Chlorate (28 Parts)

Barium Chlorate (53 Parts)

Colophony (10 Parts)

Horticultural Charcoal (5 Parts)

Dextrin (4 Parts)

Helix Blue [†]

Potassium Chlorate (48 Parts)

Copper Oxychloride (10 Parts)

Lactose (10.5 Parts)

Clear uPVC Cement (28.5 Parts)

Dextrin (3 Parts)

Helix Purple [†]

Potassium Chlorate (53 Parts)

Copper Oxychloride (10 Parts)

Strontium Carbonate (6 Parts)

Lactose (8 Parts)

Clear uPVC Cement (23 Parts)

Dextrin (3 Parts)

[†] Compositions containing uPVC must be prepared using a special technique. Information regarding preparation is provided in Appendix #1 on page. 29. under the section 'Preparation Notes for the Helix Series Pyrotechnic Compositions.'

Helix Pink †

Potassium Chlorate (53 Parts)
Copper Oxychloride (8.5 Parts)
Strontium Carbonate (7.5 Parts)
Lactose (8 Parts)
Clear uPVC Cement (23 Parts)
Dextrin (3 Parts)

Helix Black Powder Prime

Potassium Nitrate (75 Parts)
Horticultural Charcoal (15 Parts)
Sulphur (10 Parts)
+ Dextrin (5 Parts)
+ Spherical -200# Aluminium (5 Parts)
+ Red Iron Oxide (5 Parts)

Endnotes to this section:

The formulas given here have been arranged in a listed form. This is not the typical way of displaying compositions and makes the use of the above formulas unnecessarily difficult. The key formulas have been recreated on the following page in a tabular form.

The focus of this guide is not on simple nitrate-based compositions and as such they have not been recreated in this table. If such a table is desired, many already exist online and can be sourced from there.

Preparation notes for the simple nitrate-based star compositions have also not been included in this guide and can be sourced online. Conversely, preparation notes for the Helix Series Compositions have been provided and are available in Appendix #1 on page. 28. under the section 'Preparation Notes for the Helix Series Pyrotechnic Compositions.'

Further to this, Appendix #1 also contains images demonstrating the functioning of these compositions. These can be found on page. 30. under the section entitled 'Colour Testing of the Helix Series Compositions.'

Table 1.1. Helix Series Coloured Pyrotechnic Star Compositions

	Helix Red[i]	Helix Orange[ii]	Helix Yellow[iii]	Helix Green[iv]	Helix Blue	Helix Purple	Helix Pink	Helix Prime
Potassium Chlorate	70	76	76	28	48	48	48	-
Potassium Nitrate	-	-	-	-	-	-	-	75
Barium Chlorate	-	-	-	53	-	-	-	-
Copper Oxychloride	-	-	-	-	10	8	4.5	-
Strontium Carbonate	15	4	-	-	-	2	5.5	-
Sodium Oxalate	-	4	10	-	-	-	-	-
Colophony	10	8	9	10	-	-	-	-
Lactose	-	-	-	-	10.5	10.5	10.5	-
Horticultural Charcoal	1	-	-	5	-	-	-	15
Shellac	-	4	-	-	-	-	-	-
Clear uPVC Cement	-	-	-	-	28.5	28.5	28.5	-
Sulphur	-	-	-	-	-	-	-	10
-200# Aluminium	-	-	-	-	-	-	-	+5
Dextrin	4	4	5	4	3	3	3	+5
Red Iron Oxide	-	-	-	-	-	-	-	+5

A number of the compositions given here are adaptations of formulas from Hardt's 'Pyrotechnics' and Lancaster's 'Fireworks Principals and Practice.' References to the original formulas are provided as endnotes on the final page (page. 43.)

Chemical Sourcing and Synthesis Guide

Preface: Although all the chemicals in the above compositions have been acquired from OTC sources, to say they are easy to source and synthesise is inaccurate. Personally, I have managed to locate all these chemicals and chemical precursors and perform all the reactions listed below with only OTC chemicals. However, depending on your location and proficiency in chemistry, your success may vary.

Further to this, much of the information provided in this guide is only preliminary and thorough research of the relevant chemistry is required to undertake these syntheses safely and successfully. Having said that, this guide is a good repository from which one may begin.

Potassium Nitrate (KNO_3)

Potassium nitrate is considered the corner stone chemical of pyrotechnics because of its use in various invaluable compositions. Unfortunately, KNO_3 is one of the more difficult chemicals in this guide to source. Further, no reasonable synthesis can produce it. The only way to procure potassium nitrate is purchasing it either as a fertiliser, stump decomposing agent (stump remover), or meat preserving agent. The latter two of these, however, often come at very high cost. Without a doubt, best sourcing of KNO_3 for amateur pyrotechnicians is in the form of fertiliser. This can sometimes be difficult, although, to my knowledge, even very strict nations have only completely banned NH_4NO_3 fertilisers, so KNO_3 should still be possible to source.

The first instinct of many when looking for KNO_3 is to head for the local hardware store, however, in almost all cases, it will not be something they stock. What is needed is a store that specialises in the sale of farm equipment and supplies. Often a google search of ‘Rural Store,’ ‘Farm Store,’ ‘Agricultural Store,’ or ‘Farmers CO-OP’ will turn up one of these suppliers. Looking on the websites of these stores tends not to show the product as being something they stock – for legal reasons – so it’s best to call the store directly. When on the phone, instead of asking for potassium nitrate, using brand names will add legitimacy to your call. In Australia, the most common brands stocked are ‘Haifa Multi-K’ and ‘Krista K Plus.’ If this information is insufficient, asking for the chemical directly is appropriate. It is most common to find 25kg (55lb) bags being sold for around $50 USD which is a decent price, although, this can vary quite a lot.

A note to be made on purity: look at the NPK rating on the front of the bag. Pure KNO_3 has an NPK rating of 13.5-0-46.2 which is given the name ‘GG’ or ‘Green House Grade.’ Although this is best, any grade will work - just look for an NPK rating similar to the one above. Personally, as do many other pyrotechnicians, I use ‘Multi-K Classic’ with an NPK rating of 13-0-46.

Sulphur/ Sulfur

Sulphur is used primarily as a modifying agent in pyrotechnics and occasionally as a fuel in select compositions. Sulphur is a relatively easy chemical to acquire and can be purchased from a number of sources including pharmacies, hardware stores, and agricultural suppliers. The most economical way of purchasing sulphur is from agricultural stores as a fungicide in either 25kg (55lb) bags for around $40 USD, or by the kilogram, which is often also an option, costing $3-$4 USD. An alternate option available from the hardware store is 'Dusting Sulphur' which is sold for around $15 USD per kilogram. This is, in all effectiveness, the same product as that available from an agricultural supplier, although, it is much more expensive and much finer in particle size.

Charcoal

Charcoal serves as the primary fuel in a large range of pyrotechnic compositions, including black powder, charcoal streamers and charcoal-based glitters such as D1. Charcoal is quite an easy chemical to attain or produce. Around the world, large numbers of amateur pyrotechnicians produce their own charcoal by roasting splints of fresh wood in an anaerobic environment such as a paint can. The advantage of this process is the knowledge of exactly what wood is contained in the final product, a fact paramount to the production of very high-quality black powder. However, in the search for a less laborious charcoal source, I have managed to locate two forms of OTC charcoal which, when used together, can serve as an adequate alternative to home-produced charcoal in all pyrotechnic compositions I have tested to date.

For use in star compositions and as an additive to produce sparks in rocket fuel, 'Horticultural Charcoal' is used. This charcoal generally costs around $3 USD per kilogram and can be purchased from the gardening section of the hardware store. It is primarily sold as an additive to increase soil drainage. Horticultural charcoal mostly consists of hardwoods, such as Red Gum and Iron Bark, although this does vary between regions. In the US for example, most horticultural charcoal is produced using Oak. Because this charcoal is made of hardwood, its main failing is the inability to produce fast-burning black powder. Instead, for this purpose, lump charcoal is used.

Although once a rare sight, in recent years, lump charcoal has grown greatly in popularity due to a rise in demand for more 'organic' barbeque fuel options. Once something that had to be sourced from specialist suppliers, lump charcoal is now a staple found in the outdoor living sections of almost all hardware stores. Charcoal from this source can be made of various woods. Low quality lump charcoal tends to be pine. Some discretion must be taken when purchasing a bag of lump charcoal for use in pyrotechnics. When grilling, the best type of charcoal to use is one which burns and gives off heat for the longest duration, thus, hardwood is the obvious choice. As a result, all high-quality lump charcoals are made from extremely hardwoods to ensure best cooking results. Conversely, when making black powder, the lowest density wood available is desired. As a result, the best charcoal to select is almost always the cheapest one sold. To get a rough idea of which is best, it is possible to compare the size of the bags used by suppliers. As softwood has a much lower density than hardwood, the same mass of charcoal will take up a much larger space and, thus, a bag of softwood will be much larger than a bag of hardwood. What this means, in practice, is that when selecting a brand of charcoal, the best one to select will be the one which is largest for a given weight. The most common bag size sold in Australia is 10kg (22lb) and that is what I have always used to compare between brands. The one I purchase is the largest for that given mass. Generally, though, just buying the cheapest charcoal available is sufficient to ensure the highest performing charcoal for pyrotechnic applications is selected. Charcoal from this source generally costs about $1 USD per kilogram.

A note relevant to the processing of charcoal powder into differing grades such as ‘80-Mesh’ or ‘40-Mesh’ for compositions such as rocket fuel: look online for companies, often based in China, who sell small 30cm by 30cm sheets of screen for only a few dollars each. By simply searching, for example, “60 Mesh Screen” on eBay or Amazon, one is quickly able to find the appropriate screen for a desired purpose. I myself always go ‘20-mesh over 20-mesh under’ for screening, thus, if a desired powder is 60 mesh, I will make -40+80 Mesh powder, which tends to work well. One does have to frame these screens, but this is a trivial exercise considering the usefulness of being able to ascertain a specific mesh of charcoal or any other chemical.

Note also: charcoal briquettes are not a viable source of charcoal and contain several binders and additives that will almost totally destroy the effect of any composition they are used in.

Dextrin

Dextrin is used as a binding agent and occasionally a fuel in a large array of pyrotechnic compositions. Dextrin finds some niche uses in arts and crafts as a binder and glue and, thus, some have supposed it to be available for purchase through various art store chains. I have, however, never seen it being sold for such uses. Instead, the most common way to acquire dextrin is via the baking of corn-starch. Corn-starch can be sourced from the baking goods section of all grocery stores for use as a thickening agent.

Many tutorials exist describing this process which is far from complex. Simply placing grocery store corn-starch in the oven at approximately 200°C (400°F) for one to two hours with frequent mixing rearranges the molecular structure of the starch, converting it into golden brown dextrin. If more information on this process is desired, many articles exist online which are quite easy to locate.

Wheat Flour

Wheat flour is a very occasionally used fuel, modifying agent, and weak binding agent in pyrotechnic compositions. It is more common to see other chemicals doing these jobs, however, in certain cases, wheat flour is the best option. Particularly older compositions use this chemical as it was one of the few which was widely available at the time they were written.

Wheat flour can be purchased at all grocery stores in the baking section for use in baked goods. Often two forms of wheat flour are available: plain (all-purpose) and self-raising. For use in pyrotechnics, plain flour is desired, as it has no additives that can interfere with the proper functioning of the compositions it is used in.

Aluminium/ Aluminum Powders

Aluminium is used as both an agent to produce sparks and as a fuel in a large number of pyrotechnic compositions. Aluminium powders come in many different grades and are given many different names depending on the size and shape of the individual aluminium particles. Even with all these distinctions, I find that for most uses only two grades of aluminium are really needed, 'Spherical -200 Mesh Aluminium' and 'Flake Dark Aluminium.' Below are images of each of these types of powder.

Flake Dark Aluminium

Spherical -200# Mesh Aluminium

Spherical -200# aluminium is sourced from specialised craft stores which deal in supplies for resin cold casting. These stores sell aluminium powder for use as an additive to resin casts where a metallic lustre is desired. A google search of 'Resin casting supplies store' should turn up several relevant results. Like potassium nitrate, many of these stores do not list aluminium on their websites,' so giving them a call is the recommended approach. If they do not supply it, it is likely they will be able to direct you to someone who does. Aluminium from these suppliers costs around $30 USD per kilogram.

The second major type of aluminium used almost exclusively in flash compositions is 'Fine Flake Aluminium,' which goes by many names, including German Dark Aluminium, Indian Blackhead aluminium or simply dark aluminium powder. All of these have slight differences in quality due to their differing production methods, however, for simple flash boosters and small salutes, these very high-quality aluminiums can be replaced with a home-produced type of dark aluminium made by milling aluminium foil with charcoal powder in an anaerobic environment.

This process is far from safe! Safety and fire protocol must be in place if one is even considering milling their own aluminium powder. This would be inclusive, but not limited to, a remote mill stop and start mechanism, a safe and isolated milling location, and fire prevention and control methods for if an explosion of the mill jar was to occur.

Many individuals – some of whom are far from well-educated on the topic – have described the process of milling aluminium foil into dark aluminium powder so I will not go into excessive detail in this guide. Briefly summarised though, the general procedure involves using a blender to create small balls of aluminium foil which are then milled for upwards of three weeks with charcoal powder. The charcoal powder coats the aluminium as new surface area is exposed, preventing oxidation, and resulting in a very fine non-oxidised powder of aluminium. This process must be done using very hard milling media for which ¾" glass marbles often find use; however, this is very dangerous. It is far wiser to use non-sparking steal or ceramic media of the same size for this purpose. Although not recommended, if one plans to use glass marbles as media, it is necessary to ensure the glass used has no colourants or patterns contained inside and is clear glass straight through. The additives used to colour the glass make it susceptible to sparking, which can lead to an explosion of the mill jar. Ultimately, although an effective method and one I personally use, undertaking this preparation can be very dangerous and much information left out of this section must also be considered. Further research is without a doubt needed before attempting this preparation.

Sodium Bicarbonate ($NaHCO_3$)

Sodium bicarbonate, also known as bicarbonate of soda, is a modifying agent and in rare occasions a colouring agent which produces a strong yellow hue. Sodium bicarbonate is one of the easiest over the counter chemicals to find and it can be purchased at grocery stores as both a baking and cleaning product. Both grades will work equally well, however, with the far lower cost of the cleaning grade bicarbonate, it finds much more common use.

Note: if for some reason one is purchasing the food grade bicarbonate, ‘Baking Powder’ and ‘Baking Soda’ are different things. Baking soda is pure sodium bicarbonate but baking powder has numerous additives which reduce its effectiveness.

Potassium Chlorate ($KClO_3$)

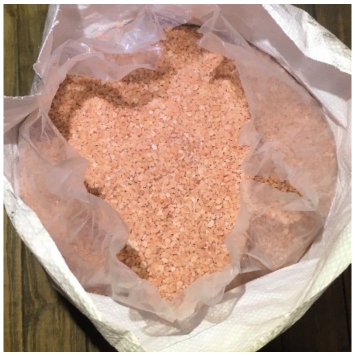
Potassium chlorate finds extensive use in pyrotechnic colour compositions, especially those which are known for their vibrancy and colour purity even with relatively simple components. Although potassium chlorate cannot be purchased over the counter, it can be produced via a process known as electrolysis. This involves passing a current through an aqueous solution of potassium chloride, whereupon the chloride is hydrolysed, liberating H_2 from solution, producing KCl, KClO, $KClO_2$ and $KClO_3$, with the major product being formed as $KClO_3$. The side products are then chemically destroyed; the chlorate is collected, dried and ground into a fine powder. This is a greatly oversimplified summary of the potassium chlorate production process and many internet articles do it much more justice than I am capable of. I can, however, discuss the acquisition of the precursors to this chemical process as well as the acquisition of the electrodes required to produce potassium chlorate and other chlorates.

In researching potassium chlorate production, one will quickly find that certain types of electrodes are required to facilitate the addition of the desired three oxygen atoms to the chloride species. Simply using copper or steel electrodes, as is common in many electrochemical processes, will result only in the production of hypochlorite and chlorite species. To produce chlorate, the most common anodes used are MMO (Mixed Metal Oxide) and graphite. Personally, I have never used graphite electrodes as my experiences with MMO anode/ titanium cathode cells have been successful enough I did not see the need to experiment further. Graphite electrodes are widely available, and I will not go into sourcing here.

MMO anodes find use in the ‘Chlorination Units’ on saltwater pools. These systems constantly pass current through salty pool water to produce NaClO which sanitizes the water. Companies which service pool equipment sell replacement electrode stacks for these systems which can be used in chlorate electrolysis. They will also have many warn out units which, in some cases, can still be used if the warn sections on the plates are not too large. The electrode spacing on chlorinator stacks is too close for chlorate electrolysis and, thus, the stacks must be disassembled and modified for correct current density. Additionally, these replacement stacks are quite expensive. Because of the cost and impracticality of modification, buying dedicated chlorate electrodes from an international pyrotechnic supplier is often more practical and will only need to be done once.

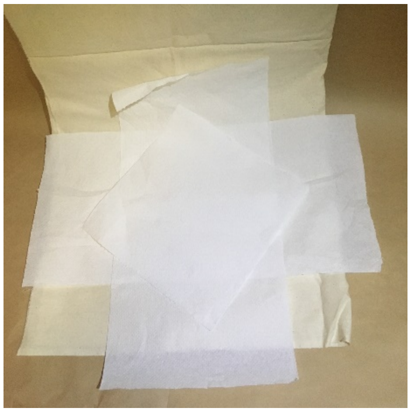
The second problem one must face in producing potassium chlorate is acquiring potassium chloride - of which I have managed to locate two sources. The first is in 'Potassium Water Softening Tablets' which are small chunks of KCl supplied in 20kg (44lb) bags for use in home water softening systems. Unfortunately, though, after extensive searching, the conclusion I made was that, in Australia at least, sale of potassium chloride for this purpose is non-existent. As a result, I have never been able to experiment with this source of KCl. This is contrasted by the US where KCl water softener is often sold at grocery and hardware stores such as Costco and Home Depot. If you live in a nation where such a source is readily available, it would be my recommended sourcing as it does not require purification before use in electrolysis.

The second source I have managed to locate is 'Muriate of Potash,' an uncommon fertiliser with the NPK rating 0-0-50. Not to be confused with 'Sulphate of Potash,' a common hardware fertiliser, Muriate of Potash, also called 'MOP,' tends only to be sold in specialised agricultural stores such as those mentioned in the section above on potassium nitrate. Unlike potassium nitrate, MOP is not recognised as a potentially dangerous chemical and, thus, precautions – such as those undertaken when purchasing potassium nitrate – are unnecessary. Simply calling up or checking on a supplier's website will list availability and pricing. Pricing for this product is approximately $30 USD for a 25kg (55lb) bag.

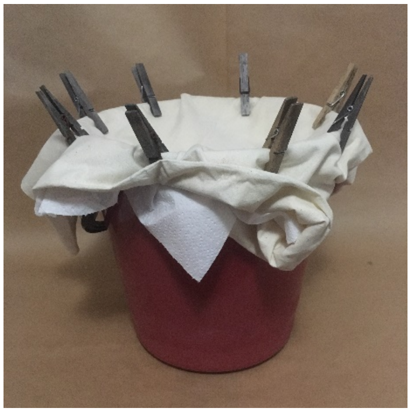


A note to be made about the use of MOP as a source of KCl: unlike the water softening equivalent, fertiliser grade KCl almost always comes coated with a waxy red substance covering the crystals and locked within the crystal structure. Due to the insoluble nature of this coating, it can be removed by first dissolving the crystals in hot water, followed by filtering the solution. However, finding a filter that can trap the waxy coat can be a challenge. After many failures and upwards of 15kg of chloride wasted, the final solution I found is shown below. This filtration setup works to give a crystal-clear solution of KCl with only a single hot filtration, leaving a filtrate that can be added directly into an electrolysis cell.

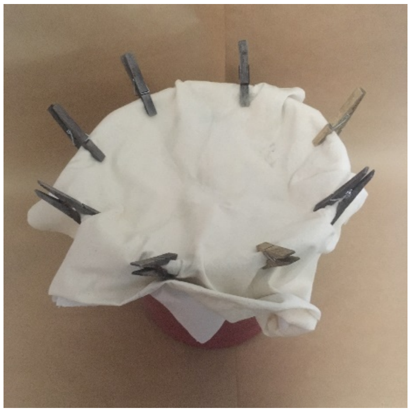
Filter Paper Setup



Filtering Setup Side View



Filtering Setup Top View



As shown in the images above, the setup used for filtering consists of a bucket onto which is attached a specialised filter paper. This filter paper is made by placing two, two sheet pieces of disposable kitchen towelling onto a piece of cloth, each offset by 90° to each other, followed by a third sheet placed 45° offset from the first two sheets (Image: Filter Paper Setup). On top of this, a second piece of cloth is placed to create a sandwich: cloth, paper towelling, cloth. In the image above, instead of a second sheet of cloth, the filter is made from one piece of cloth doubled over with the towelling sandwiched in the centre. When I first tested this and before purchasing a dedicated sheet of cloth, I used two old shirts with the paper towelling sandwiched in the centre which worked equally well. The main point of the cloth is only to stop the towelling from ripping. The cloth itself is not a particularly good filter and alone lets a large amount of the wax through. The proceeding two images show the filter as it is pegged to a bucket and ready to have liquid poured into it. The pegs hold the filter onto the bucket while the solution is passing through and allow easy removal when the process is complete.

The general procedure for this preparation is first to weigh 400g of chloride for every litre of cell volume to be filled. This measured KCl is then placed into a large pot along with a volume of water respective to the volume of the cell. This water is best boiled before the addition although this is not strictly necessary. The pot of water is then placed onto a burner or stove top and brought to a temperature high enough that all the KCl dissolves leaving a bright red suspension. During this step, the solution must be heated well above the 40°C required to dissolve the chloride as the solution will cool very quickly once off heat and going through the filter. Bringing the solution to a boil is not necessary, however, I would hazard heating much below this. Raising the solution to at least 80°C will generally be sufficient. Once the solution has been brought to the desired temperature, it can be poured through the filter yielding a clear solution out the other side. This solution can then be added directly into an electrolysis cell to produce potassium chlorate

If potassium chlorate made via this method is to be used in colour sensitive star compositions such as blue, purple or pink it must first be recrystalised. This is due to the sodium contamination present in agricultural KCl. A recrystallisation removes this contamination. Information on this procedure has been provided in Appendix #1 on page. 36. under the section entitled 'Recrystallisation of $KClO_3$ for Sensitive Star Compositions.'

Barium Chlorate ($Ba(ClO_3)_2$)

Barium chlorate is a strong oxidiser used as a dual colouring and oxidising agent in both historical and modern-day compositions. Due to its high price and sensitivity issues it is often combined with potassium chlorate. Like potassium chlorate, barium chlorate cannot be purchased directly, however, it can be synthesised via electrolysis.

The process of electrolysis to produce barium chlorate is almost identical to that used to produce potassium chlorate, thus, it will not be covered in this section. However, there are some key differences which are discussed below.

This preparation deals with toxic heavy metal in its soluble form. The LD50 for soluble barium compounds is less than 150 mg/kg. This means that for the average male, 10.5g of soluble barium is enough to kill! The information provided here is not sufficient to undertake this procedure safely. Before attempting this preparation, one must first research the further risks of this synthesis and put in place all relevant safety protocol.

The first step in preparing barium chlorate is to produce a solution of barium chloride which can undergo electrolysis. However, unlike potassium chloride, barium chloride has no domestic or agricultural uses and must be synthesised. To do this, one must first locate a source of barium. The most viable source for this is in pottery grade barium carbonate ($BaCO_3$) which is sold as an additive for ceramic glazes. Most ceramic supply stores will stock this as it is quite a common and benign chemical. Its price ranges from \$5-\$10 USD per kilogram depending on the source and the quantity purchased.

Once a source of barium carbonate has been acquired, the next stage of the preparation is reacting this carbonate with strong HCl to displace the CO_3^{-2} species and substitute it with a Cl^- species. Below this reaction is shown.

$$BaCO_{3_{(s)}} + 2HCl_{(aq)} \rightarrow BaCl_{2_{(aq)}} + H_2O_{(l)} + CO_{2_{(g)}} + Unknown\ Precipitate$$

Notice the presence of an 'Unknown Precipitate' in the equation. Although in ideal conditions the $BaCO_3$ would react completely to yield a clear solution of chloride, unfortunate, this does not occur. The results of your experimentation may vary, although, in my personal experience, after adding a stoichiometric volume of concentrated 31.45% (10M) HCl purchased from the hardware store, a white powder always remains in suspension and as a sludge at the bottom of the reaction vessel. Further, even after the addition of more HCl and water to this sludge, no reaction is observed, implying both very low solubility in water and non-reactivity with HCl. After further testing, I came to no conclusion as to what this material was, although, upon drying and weighing, it was determined that this powder constituted approximately 10% of the initial barium carbonate sample.

The electrolysis process which is to be performed in later steps of this production requires a solution of reasonable purity, thus, the next stage of this preparation is removing this insoluble sludge from the $BaCl_2$ solution. To achieve this, I have attempted many different techniques, however, after extensive testing, the method which I determined to be most effective was filtration. To undertake this separation, the solution is passed once through the filter setup specified for purifying agricultural grade potassium chloride. This setup is described in the above section on potassium chlorate and shall thus not be restated here. Refer to page. 11. for information regarding this filtering apparatus.

Irrespective of the method one uses to remove the sludge – which may in fact not even be present depending on the quality of your carbonate source – the next stage in barium chlorate manufacture is electrolysis of this barium chloride solution. If the volume of solution remaining after this neutralisation reaction exceeds the volume of your cell, the solution may be left out in the sun for a number of days to remove excess water, however, this should generally not be an issue. In fact, it is more likely the solution will need to be diluted to reach the desired volume. Regardless, once the desired volume is reached, the solution is set up for electrolysis. This process generally takes between seven and ten days to yield a solution of barium chlorate, although, these numbers are drawn only from my personal experience.

Note here that there are some key differences between the electrolysis of barium and potassium chlorate which I have observed that the reader may be helped having known. Firstly, unlike potassium chlorate electrolysis, the electrolysis of this pottery grade barium chlorate quickly turns a deep grey colour and precipitates small white flakes on the bottom of the cell. This is nothing to be alarmed by; the reaction is still proceeding. My understanding is that this colour change is due to side reactions occurring in solution because of impurities in the carbonate source.

Secondly, unlike the electrolysis of potassium chlorate which yields an evident crop of crystals at the bottom of the cell, the solubility of barium chlorate is so high that, once formed, the barium chlorate remains in solution. This is not an immediate issue and is dealt with in subsequent steps, however, it does make it quite difficult to determine the end point of the electrolysis. This is an important point to be able to identify as a large reduction in the concentration of reactants can lead to damage of the MMO anode. If the reader has access to a hydrometer this can be used to determine the end point of the electrolysis, if not, the cell should simply be run for the same time as a potassium chlorate electrolysis of the same size. Other than these two distinctions, the electrolysis of barium chlorate is identical to that of potassium chlorate, i.e. the electrodes, electrode spacing, cell design and power supply can all be identical.

Reaction Mechanism

$BaCl_{2(aq)} + 6H_2O_{(l)} \rightarrow Ba(ClO_3)_{2(aq)} + 6H_{2\,(g)}\ (Under\ Ideal\ Conditions)$

$Cl^- + O^{-2} \rightarrow ClO^- + 2e^-\ (First\ Oxidisation)$

$ClO^- + O^{-2} \rightarrow ClO_2{}^- + 2e^-\ (Second\ Oxidisation)$

$ClO_2 + O^{-2} \rightarrow ClO_3{}^- + 2e^-\ (Third\ Oxidisation)$

Under ideal conditions, the chloride ion is oxidised three times to produce the final chlorate ion, passing through the hypochlorite and chlorite intermediates. However, in reality, the electrolysis produces a mixture of all three of these species, in varying proportions, in accordance with the conditions in which the electrolysis takes place. This is more so the theory of electrolysis than the practice and I will not go into excessive detail about the chemistry here. Although, needless to say, after the completion of the electrolysis, these species must be destroyed. Note the barium spectator ion is emitted from these half reactions.

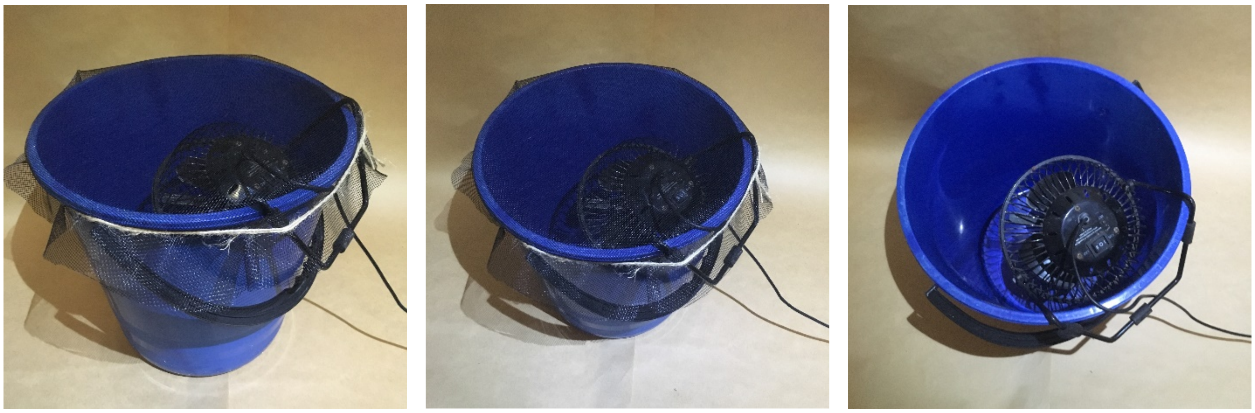
After the electrolysis has reached completion, or a judgment call is made, the solution exists as a suspension of black particles. Once power is removed, the electrodes and lid are taken off the main cell and the lid is replaced with a piece of saran wrap or another appropriate cover to prevent dust from entering the electrolyte. This solution is then sat on a bench overnight to cool to room temperature and allow the floating particulate to settle to the bottom of the cell. This leaves a crystal-clear solution on top with a dark brown precipitate settled at the bottom. Once this separation is observed, the supernatant can be decanted off into a separate container being careful not to allow any of the sediment into this first pour. This should leave at most a few hundred millilitres at the bottom of the cell which contains the black particulate. This can either be discarded and counted as loss or passed through a coffee filter to yield a solution that can be added to the supernatant.

After completing these steps, a clear solution of barium chlorate is produced, however, unlike when producing potassium chlorate which is now precipitated by cooling the solution, the solubility of barium chlorate is so high – even at 0°C – the only viable method for its recovery is the evaporation of the water it is solvated in. This is achieved most simply by placing the solution in a wide mouth bucket for several weeks outside until the water is evaporatively removed. For the impatient among us – myself included – a method to increase the rate of this process is to use a small desktop fan which can be purchased from a department or discount store. Secured over the lip of the bucket and aimed at the liquid, this can cut the drying process time in half. Images of this setup are provided over the page. Note that the netting attached to the top of the bucket is to prevent unsuspecting insects from entering and getting caught in the solution, contaminating the final product.

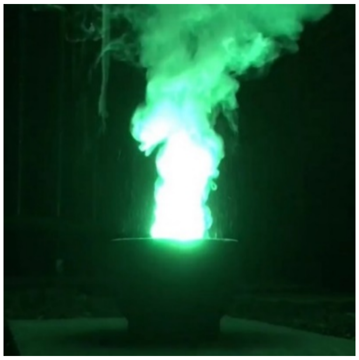
After one to two weeks have passed, this evaporation method is able to remove almost all the water from the large 5L batches of electrolyte I generally run. From here, the remaining water can either be removed by continuing this process in the evaporation bucket or by removing what remains and placing it on trays in the sun. Both of these processes, however, leave the final barium chlorate with a slight yellow tint as opposed to the pure white one would expect. To fix this, I have found that placing the almost dry chlorate from the evaporating bucket onto metal trays and roasting it for about 30 minutes at 100°C (212°F) removes the yellow hue and leaves the powder a pure bright white. It is necessary to purchase a small toaster oven for this purpose, which can often be found on local classifieds, as barium chlorate is much too toxic to place in an oven intended for food.

I have, as of yet, not found an explanation for why this process turns the crystals white. Someone has proposed the barium chlorate at high temperature was oxidising the contamination into some other form, although, I find this unlikely. Another proposal was that the heat was liberating the barium chlorate's waters of crystallisation changing its colour, however, I doubt this also as the colour change never reverts. In any case, it is a nice aesthetic touch.

Setup of an Evaporating Bucket



Whatever the process employed, once this final drying has been completed, the powder is then crushed or milled and placed into storage. To the right is an image of barium chlorate made via this preparation mixed in an 80:20 ratio with shellac burning in a small crucible. Even from very close up when colour compositions can look washed out, the barium chlorate clearly gives a very pure green. The quality of this colour is difficult to describe and even more difficult to capture on camera, but it is enough to say that it is not easily forgotten. Though the process to produce this barium chlorate is long and quite involved, the quality of green achievable is well worth the time.



Copper Oxychloride ($Cu_2(OH)_3Cl$)

Copper oxychloride is an uncommon compound of copper which finds some limited use as a fungicide in agriculture. The main uses of copper oxychloride in pyrotechnics are as a colouring agent in blue and purple stars, and as a catalyst in various rocket fuels. **If available, copper oxychloride fungicide should be used**. Sourcing for this product is discussed separate to this section. Information regarding this source can be found on page. 32.; the following covers only the chemical synthesis of copper oxychloride.

Production of copper oxychloride can be achieved by a number of syntheses and the method which I cover here is simply the one I use; many others also exist. One of the most popular alternative methods is the electrolysis of copper metal to cuprous oxide (Cu_2O) followed by a reaction with HCl to yield cupric chloride (CuCl) and then oxidation with atmospheric oxygen. Many procedures for this type of synthesis are available so I will not go into detail here.

The method I employ for producing copper oxychloride starts with the reaction of Cupric Oxide (CuO) with HCl followed by an addition of potassium hydroxide (KOH) to precipitate copper oxychloride. An alternate method which I have employed in the past is the substitution of KOH with Potassium Carbonate (K_2CO_3) which yields oxychloride via a slightly different pathway. Both are discussed here, although, I will preface this synthesis by saying I prefer the KOH method due to the speed at which it can be conducted. The K_2CO_3 method takes much longer due to the foaming that occurs as a result of liberated CO_2 and the time it takes for this to subside.

The first step in producing copper oxychloride is preparing a solution of $CuCl_2$ which I personally do by adding a stoichiometric quantity of 9.9M 31.45% HCl – from the hardware store – to about 200g of cupric oxide (Black Copper Oxide) (CuO). Black copper oxide is sold at almost all pottery stores as a colourant for ceramics ranging from $10-$50 USD per kilogram.

Using this amount of CuO gives a respectable yield without being too large a batch to handle. Below is shown the chemical equation for this reaction.

$$CuO + 2HCl \rightarrow CuCl_2 + H_2O$$

Once this HCl has been added, a dark green solution of solvated copper chloride is produced as a complex in the form $[CuCl_4]^{-2}$ with solvated $[Cu]^{+2}$

$$CuCl_{2(s)} + H_2O_{(l)} \rightarrow [CuCl_4]^{-2}{}_{(aq)} + [Cu]^{+2}{}_{(aq)}$$

An alternate procedure to attain a solution of copper chloride is first reacting copper sulphate pentahydrate – sold as a fungicide in just about every hardware store – with a stoichiometric amount of potassium carbonate to yield copper carbonate. This copper carbonate can then be reacted with HCl, liberating CO_2, and yielding a solution of copper chloride. Further information on this alternate procedure can be found online and as such will not be covered here.

Once a solution of copper chloride has been attained, the next stage in the preparation is to convert it to copper oxychloride by the addition of either KOH or K_2CO_3. Both reactions are written out below.

$$2CuCl_2 + 3KOH \rightarrow Cu_2(OH)_3Cl + 3KCl$$

$$4CuCl_2 + 3K_2CO_3 + 3H_2O \rightarrow 2Cu_2(OH)_3Cl + 6KCl + 3CO_2$$

If the KOH method is used, the reaction must be done using a solution of KOH as opposed to direct addition. The concentration of this solution should be in the region of 2.5M, however, the exact concentration is of little concern. When using K_2CO_3 a solution should also be used although this is not strictly necessary. The concentration of this solution should be in the region of 3.5M, but again, the exact concentration is not critical.

KOH is sold at soap supply and organic product stores for use in producing liquid soaps through saponification. It generally costs between $5 and $10 USD per kilogram. K_2CO_3 can be found at most pottery supply stores under either the name 'Potash,' or more commonly 'Pearl Ash,' for use as a flux in ceramics. The price of K_2CO_3 from this source is generally around $5 USD per kilogram.

Notes for producing oxychloride via the KOH method: Firstly, the addition of the KOH to the solution must not be done too fast or at too high a temperature. These conditions are capable of leading to the production of the undesired side products CuO and $CuCl_2$ which contaminate the oxychloride. In the case of CuO, this compound can be preferentially produced over the oxychloride, meaning no oxychloride is produced at all. Secondly, the solution must not be allowed to stand upon addition of the solutions as such conditions lead to undesired side reactions. The addition of the solutions should be done subject to very strong stirring. Finally, although stoichiometrically, one and a half moles of KOH are required per mole of $CuCl_2$, slightly basic conditions are required to achieve maximum yield, and mitigate safety concerns in regard to acidic chemicals and chlorates, thus, a slight excess of KOH is always required.

$$CuCl_2 + 2KOH \rightarrow CuO + 2KCl + H_2O\ (CuO\ Side\ Reaction)$$

Regardless of the method used to convert the $CuCl_2$ to copper oxychloride, the final stage of the preparation is separating the oxychloride from suspension. This is done by allowing the suspension to stand, upon which the insoluble copper oxychloride settles to the bottom of the reaction vessel. The KCl supernatant is then decanted off into a separate vessel and the oxychloride is rinsed onto a filtering setup with distilled water. Once in a funnel, it can be rinsed again with distilled water and left out on a watch glass or in a cool oven to dry. Finally, it can be broken up and stored for later use.

Simplified Synthesis

In the above section I have not specified the actual amounts of the various chemicals to be used and have simply left the calculations to the reader. To save the reader time in completing these calculations, I have below laid out an example preparation of 100g of copper oxychloride in full. This preparation can be scaled if desired.

Preparation of Solution A

Into a clear glass vessel is added 75g of copper oxide (CuO) followed by 190ml of HCl. This solution is stirred for 1-2 minutes or until no CuO can be seen on the bottom of the vessel. If, after stirring, solid CuO is still present, the acid used has deteriorated and reduced in concentration. If this occurs, additional HCl should be added in 5ml increments followed by stirring until all the CuO has reacted and no solids are present. A small amount of inert sediment may still be present, but this will not affect the reaction.

Note: Before beginning the final addition, both solutions should be allowed to cool to room temperature

Preparation of Solution B

Preparation using KOH

Into a heat resistant glass vessel is added 580ml of cold distilled water. Into this water is introduced 110g of KOH. This solution is then stirred until all the KOH has dissolved. Note the dissolution of hydroxides is exothermic and the solution may become warm or hot. Observe relevant safety procedure.

The calculations for this solution are done assuming, as is most common, the KOH is in a monohydrated state. This is important as it quite drastically changes the amount used. If this fact is not accounted for, the amount of KOH present will be insufficient which yields a product contaminated with HCl and soluble copper. Such contamination is highly undesired due to the safety concerns it brings. In addition to this, a 5% excess of KOH has been accounted for to maximise yield.

Preparation using K_2CO_3

Into a glass vessel is added 300ml of distilled water. Into this water is introduced 100g of dried/ anhydrous K_2CO_3. This solution is then stirred until all the K_2CO_3 has dissolved.

Final Preparation

With very strong stirring **SOLUTION B** is poured slowly into **SOLUTION A**. Note the order of this addition is important. If the K_2CO_3 pathway is used it is wise to perform this reaction in a large 10L bucket. This will limit the potential for foam over. If the KOH pathway is used, the volume of the reaction vessel need only be large enough to accommodate the total volume of the two solutions with some leeway for stirring.

Once the two solutions have been combined the reaction can be left to stand and the oxychloride can be separated. The theoretical yield for this reaction is 100g of $Cu_2(OH)_3Cl$, although, in reality, the yield is always somewhat less.

Clear uPVC Cement $(C_2H_3Cl)_n$

PVC, or polyvinyl chloride, is the chain polymer of the vinyl chloride monomer, which is used primarily as a chlorine donor in pyrotechnic compositions. Traditionally, PVC is used in a powdered form to add chlorine in situ to a star as it burns. Unfortunately, sourcing powdered PVC over the counter is reasonably challenging. One source does exist in the form of ‘PVC Dry Blend Resin’ which is discussed as an alternative source in Appendix #1 on page. 34, but this is hard to come by. In the compositions provided in this guide, powdered PVC is instead replaced with an alternate source of PVC which is more readily available to the average amateur – PVC cement.

Before attempting to prepare a composition containing PVC cement, the reader is recommended to look over the guide for the preparation of PVC cement compositions provided in Appendix #1, on page. 29., under the subsection ‘Helix Blue Helix Purple and Helix Pink.’ The procedure is quite different from that which is normally employed.

‘PVC cement,’ also called ‘PVC glue,’ is a thick, often coloured liquid, used to join PVC pipes together by a process known as solvent welding. It is generally a mixture of volatile solvents such as MEK and acetone with some amount of dissolved PVC. When applied to pipes, the solvent evaporates leaving the PVC behind which creates the join. There are far too many forms of PVC cement to be covered here, but I will briefly go into some preliminary information which will aid in the selection of an appropriate cement.

Firstly, a note on forms of cement that are available. At least here in Australia, the two main types of cement sold are ‘uPVC cement’ and ‘cPVC cement.’ These also take the names ‘non-pressure cement’ and ‘pressure-cement’ respectively. I won’t go into why exactly this is the case but note here that the uPVC cement is desired. This is because it has more actual PVC resin and thus less of it must be used to achieve the same results. Although cPVC cement could no doubt be used, the amount included in the composition would need to be adjusted up slightly.

Secondly, a note on ‘weight.’ In the US at least, it seems that PVC cement tends to be sold in terms of its ‘weight.’ This measurement is the way industry classifies the viscosity of various cements. The assumption may be made that higher weight product has more resin included which increases its viscosity. This, however, is not generally the case. Higher weight products in fact simply have thickening agents in them but no more actual PVC. Because of this, there is no advantage to buying the higher weight products and they should generally be avoided. Simply using regular weight/ standard weight cement is best.

Thirdly, a note on actual PVC percentage. The reader may very well be interested to know exactly how much PVC is contained in these products. Unfortunately though, I cannot give a definitive answer. I have – from various sources – read that the percentage of PVC in PVC cement is as low as 10% or as high as 24% and have no real way of confirming where in this range it lies. I would suppose it depends on the brand and cement type, but this range is still very large considering. One thing I can say is that when the cement is evaporated the content of solids is approximately 22% by weight, however, this may be no indication of how much PVC is actually present. It is reasonable to expect there are some fillers included, but how much this adds to the content of solids I do not know. The testing I have done seems to indicate the true PVC percentage is somewhere in the region of 18% with the brand I purchase. Consequentially, that percentage is the one used to develop the compositions cited in this guide. It is quite reasonable to assume that if the reader is purchasing a similar type of PVC cement, this number will be more or less accurate.

If the reader intents to adapt some other composition for use with PVC cement they may be helped having known that – assuming a PVC concentration of 18% – to convert from standard powdered PVC to PVC cement, the percentage of PVC called for must simply be multiplied by 5.56. For example, if a composition calls for 7% PVC powder, the amount of PVC cement needed will be 7×5.56 ≈ 39%. This will of course send the total 'parts' of the composition well over 100, but, if desired, the whole formula can be rescaled so it once again sums correctly.

Finally, I will briefly mention that for obvious reasons clear PVC cement is desired over the dyed/ coloured product. I don't imagine the impact of the dye would be that great, but I have never tested this as the clear cement seems to be universally available and I did not see the need to do needless research. In any case, there is no need to introduce another variable which could otherwise be avoided.

Colophony

Colophony is a very widely utilised natural resin which goes by several names including rosin, vinsol resin, colophonium, Greek pitch and many more. In pyrotechnics it is most commonly known as vinsol resin or simply colophony as I have referred to it here. In compositions, colophony acts as a fuel and most commonly finds use in chlorate-based stars. For this purpose, it used to be much more widely used, although, increasing prices drove its use down in favour of cheaper more versatile fuels such as red gum. Luckily, colophony is still widely available to individuals through various sources. Because of how extensively colophony is used, it is not possible to list all sources, however, I will discuss the two which are most easy to come by.

The first source of colophony, which is by far the easiest to locate, is as 'rosin' from the local music store. Blocks of colophony are sold here for application to the bows of violins and alike stringed instruments. This source of colophony is very pure and easy to come by, unfortunately though, it is quite expensive. A much less expensive source of colophony can be found at stores which specialise in the sale of supplies to individuals for producing organic products such as soap. In Australia, such stores are often known simply as 'Organic Supplies Stores.' These retailers stock colophony either under this name or as 'Pine Rosin' or 'Gum Rosin.' It is sold from these stores primarily for production of beeswax food wraps. Colophony from this source is approximately $15 USD per kilogram. Colophony can also be recovered directly from pine trees as it seeps from damaged areas of the trunk, but this method is not covered here.

Shellac

Shellac is a golden yellow to red powder secreted by the lac bug. In the past, it was utilised extensively as a wood finish and additive in varnishes, however, due to its high price, it has fallen out of favour in recent years. In pyrotechnics, shellac is used as a pure burning low-temperature fuel and occasionally as a very weak, often secondary, binding agent.

Compared to fifty years ago, shellac has become much more elusive, but most major hardware stores still stock shellac flakes, located in the painting section. If the local hardware store turns up nothing, try a dedicated art store where shellac is often sold to individuals wanting to mix varnishes. If neither of these stores stock shellac, try searching the internet for a dedicated hobby painting store which will almost always stock shellac or be able to give direction on where to locate it. Shellac from these sources costs between $40 and $100 USD per kilogram.

Lactose ($C_{12}H_{22}O_{11}$)

Lactose is a fine white powder used commonly as a fuel in pyrotechnic compositions where potassium chlorate is the main oxidant. When used in this way, lactose burns at a very low temperature making it ideal for use in blue star compositions.

Lactose powder can be purchased at almost all brewing stores where it is sold as an additive for the brewing of alcoholic beverages. From this source, lactose is most commonly sold in small 100g bags. Although the price can vary depending on the amount purchased, lactose from brewing stores tends to cost between $7 and $10 USD per kilogram

Sodium Oxalate ($Na_2C_2O_4$)

Sodium oxalate is a quite commonly utilised pyrotechnic chemical which finds use as both a delay and colouring agent. In potassium-chlorate-based yellow stars, cryolite is more commonly used, although, I am unaware of any over the counter source of this.

There are two main pathways to synthesise sodium oxalate and I will cover both here, however, it is worth noting the NaOH pathway is preferred by this author because of the speed at which it can be conducted and the higher yield it lends itself to.

Note the beginning of these two preparations is identical and as such is laid out here only once

The first step in making sodium oxalate is creating a close to saturated solution of oxalic acid dihydrate ($C_2H_2O_4 \cdot 2H_2O$) at 60°C (120°F). Oxalic acid can be purchased as a rust and stain remover from most hardware stores for between $10 and $15 USD per kilogram. This solution must be prepared hot because of the relatively low solubility of $C_2H_2O_4$ in cold water. Making the solution in this way reduces the total amount of water needed for the synthesis and thus reduces the loss of product. The saturation point of oxalic acid in water of this temperature is approximately 4M. Once a solution of oxalic acid at this concentration has been prepared, the next step in this synthesis is reacting it with a basic sodium salt to yield sodium oxalate. A number of salts can be used for this, however, covered here are the two most common - sodium bicarbonate and sodium hydroxide.

Preparation Using $NaHCO_3$

The first pathway which will be discussed is that using sodium bicarbonate. Converting the solution of oxalic acid attained in the previous step to sodium oxalate using sodium bicarbonate can be done in two ways. Either, the salt can be added directly into the solution which has been created, or, the salt can be first brought into solution and then the solutions can be combined. The latter of these options gives a more complete reaction and thus is the one which shall be covered here.

When creating a solution of sodium bicarbonate for this reaction, the minimum amount of water possible should be used to limit the loss of the final product. Sodium bicarbonate is reasonably insoluble in water, so this solution is best prepared using boiling water. The saturation point of sodium bicarbonate at this temperature is approximately 2.8M, although, unless a hot plate is used, the solution is made somewhat less concentrated than this to account for cooling. As this solution is very close to saturation, it will most often be necessary to add an additional volume of boiling water to dissolve all the bicarbonate and ensure it remains solvated as the liquid cools. This is quite normal and is to be expected.

Once the solutions have been prepared, the oxalic acid solution should be transferred into a large 10L bucket to prevent foam over during the reaction. The sodium bicarbonate solution can then be slowly added giving time for the liberated gas to dissipate. After the two solutions have been completely mixed and stirred to ensure a complete reaction, the resultant can be left to stand. Upon standing, small crystals will begin to form. The reaction taking place is given below.

$$C_2H_2O_4 \cdot 2H_2O + 2NaHCO_3 \rightarrow Na_2C_2O_4 + 2CO_2 + 4H_2O$$

Following this, there are two ways to recover the crystals from the large amount of solution which remains. The first method involves chilling the sodium oxalate solution to at least 20°C (70°F) or, ideally, to just above freezing. Sodium oxalate is quite insoluble in water and at lower temperatures the majority will crash out of solution. The theoretical maximum recovery for this method is approximately 80%. Alternatively, and this is the method I recommend, the solution can be left to evaporate down. This will greatly increase the recovery but does take much more time. If all the water is evaporated the theoretical yield is 100%. To speed this process up, an evaporation bucket can be used such as is described in the subsection above entitled ‘Setup of an Evaporating Bucket’ on page. 14. Even still, the evaporation takes considerable time. Unfortunately, this problem is one of the trade-offs which exists when using the $NaHCO_3$ method and is one of the two primary reasons I preference the NaOH method.

Disadvantages and Dangers of the NaOH Pathway

Before I detail the NaOH preparation I would like here to discuss the key disadvantages and dangers of using this pathway. Because this sodium oxalate is going to be used in potassium-chlorate-based pyrotechnic compositions, it is quite important to ensure no oxalic acid remains unreacted contaminating the final product. This acidic compound has the potential to destabilise chlorate compositions increasing sensitivity and in extreme cases even resulting in spontaneous combustion. To further complicate issues, contamination from NaOH is also undesired as this will result in a strongly basic final product which comes with the same stability problems.

When using sodium bicarbonate for this synthesis, this issue is of much less concern for two reasons. Firstly, it is clear when using bicarbonate at what point the reaction has ceased. The reaction of oxalic acid and bicarbonate evolves a large amount of CO_2 gas which can be used as an indicator for the completion of the reaction. When bubbling stops, the reaction is clearly over. Secondly, adding even a large excess of carbonate is of no real concern. Sodium bicarbonate forms a buffer at around pH 8 and thus, even in large quantities, has little effect on the pH of the final product. Because of this property, an excess of sodium bicarbonate is always used to ensure no acid remains.

When using NaOH neither of these key advantages can be utilized and the need arises to work around the issues this creates. The obvious solution to this is using accurate amounts of each of the reagents to ensure a complete reaction takes place, however, this is in practice not possible. Predominantly, this is because NaOH has a varying molar mass due to its extreme hydroscopic nature. Hardware store samples of NaOH tend to be the monohydrated form, although, depending on the age of the sample, this is not always the case. Regardless, even using a completely new sample of NaOH is not sufficient to achieve perfect balancing of the reagents and will still result in a significant excess of one compound. As such, another solution must be employed.

Destroying these reactants can likely be done by several methods, however, the way I have approached the problem is by using a very weakly basic salt. This is capable of acting as a base when reacting with the oxalic acid and as an acid when reacting with the sodium hydroxide, thus, destroying both chemicals. Many weak bases can be used but the one which I have employed is sodium bicarbonate due to its ease of acquisition. After conducting the main reaction, a small amount of sodium bicarbonate powder can be added to the supernatant followed by stirring until no reaction is observed. When this point is reached the reaction is complete and all reagents have been destroyed. These destruction reactions are shown below.

$$1.)\ C_2H_2O_4 \cdot 2H_2O + 2NaHCO_3 \rightarrow Na_2C_2O_4 + 2CO_2 + 4H_2O$$

$$2.)\ NaOH + NaHCO_3 \rightarrow Na_2CO_3 + H_2O$$

Although $NaHCO_3$ generally acts as a base, it is a far weaker base than NaOH which allows it to act as an acid in this reaction and accept a H^+ ion.

The products of these reactions will still be present in the supernatant, but this is not of any great concern. To further mitigate this problem though, an excess of oxalic acid is used in this pathway so there is very little chance of NaOH ever being present. This means that in almost all cases reaction #1 is the reaction which occurs. Observe here that the product of reaction #1 is, in fact, sodium oxalate which is the desired product. This is why an excess of oxalic acid is used. Further, even in the rare case NaOH is in excess and reaction #2 takes place, the sodium carbonate produced is only a weak base and poses no risk in the small quantities it will be present in.

Note that this section was only included to justify and explain theoretically what would otherwise seem like quite an odd procedure when viewed alone in the following preparation. Information regarding concentrations and amounts of bicarbonate to be added are detailed in the full synthesis which follows.

Preparation Using NaOH

The second common salt used for this preparation is sodium hydroxide. NaOH can be purchased quite cheaply from the hardware store where it is sold either under its chemical name or as ‘Caustic Soda.’ It is generally quite cheap from this source, ranging from $5-$10 USD per kilogram. In the opinion of this author, NaOH is the best salt to use for this preparation. If using NaOH for this preparation, a solution of 10M concentration should be prepared and a stochiometric quantity poured all at once into the oxalic acid solution. After the two solutions have been completely mixed and stirred to ensure a complete reaction, a precipitate will settle quite quickly from the solution. This precipitate is the sodium oxalate. The reaction taking place is shown below.

$$C_2H_2O_4 \cdot 2H_2O + 2NaOH \rightarrow Na_2C_2O_4 + 4H_2O$$

Once this addition is completed, the next stage in the preparation is destroying all excess reagents. This is done by adding sodium bicarbonate in small increments until a reaction ceases to occur. The size of the increments added should be approximately 5% the weight of oxalic acid used. Generally, 3-5 additions each followed by stirring will be needed to destroy all remaining reagents. Once the addition of bicarbonate no longer causes a visible reaction, one extra increment should be added to ensure an excess of bicarbonate exists and there is no possibility of any reagents remaining.

After having completed this chemical destruction step, a large amount of white crystals will have formed and settled to the bottom of the reaction vessel. These crystals are best left for approximately 30 minutes which will cause them to coalesce into one solid mass. After said time the supernatant can be decanted leaving behind only the crystals which will stay stuck to the bottom of the vessel. To increase the yield, the solution can be chilled, however, I do not see this step as justified. The theoretical recover if the separation is done at room temperature is 88% and chilling only increases this to 91% which is a reasonably small increase considering the extra time chilling requires.

Simplified Synthesis

In the above section I have not specified the actual amounts of the various chemicals to be used and have simply left the calculations to the reader. To save the reader time in completing these calculations, I have below laid out an example preparation of 100g of sodium oxalate in full. This preparation can be scaled if desired.

Preparation of Solution A

Into a heat resistant glass vessel is added 250ml of boiling water at 100°C (212°F). Into this water is introduced 94g of oxalic acid dehydrate. This solution is then stirred until all the oxalic acid has dissolved.

Note: do not allow the solutions to cool before performing the final addition

Preparation of Solution B

Preparation using $NaHCO_3$

Into a heat resistant glass vessel is added 600ml of boiling water at 100°C (212°F). Into this water is introduced 135g of sodium bicarbonate. This solution is then stirred until all the sodium bicarbonate has dissolved. If not all the sodium bicarbonate dissolves, boiling water can be added in 50ml increments followed by stirring until total dissolution occurs.

The amount of bicarbonate used here is in 5% stochiometric excess to ensure no oxalic acid remains.

Preparation using NaOH

Into a heat resistant glass vessel is added 150ml of cold tap water. Into the water is introduced 60g of NaOH. The solution is then stirred until all the NaOH has dissolved. Note the dissolution of hydroxides is exothermic and the solution may become warm or hot. Observe relevant safety procedure.

The amount of NaOH used here is based on a stochiometric calculation assuming an anhydrous reagent. In reality, the NaOH will be hydrated to some degree. This means there will be a slight excess of oxalic acid which is important for the reagent destruction step.

Final Preparation

Preparation using $NaHCO_3$

The entirety of solution A is transferred into a large 10L bucket to limit the potential for foam over. Once the solution is in the bucket, solution B is poured incrementally into solution A. This will produce a large amount of foam which must be allowed to subside between additions.

Once the two solution have been added together, approximately 850ml of a sodium oxalate solution will remain with a large amount of white crystals in suspension and on the bottom of the reaction vessel. Separating these crystals can be done by chilling or evaporation, see main synthesis above.

Once the crystals have been separated, they can be placed on trays in the sun or in a cool oven to dry, then crushed and stored for later use.

Preparation using NaOH

Into a vessel of at least 500ml is poured the entirety of solution A. Following this is added solution B. There is no need to do this incrementally and the entire solution can be added at once. After a few seconds of the solutions having been mixed, a white precipitate forms making the solution progressively cloudier until eventually it becomes totally opaque. When this occurs, the solution is briefly stirred to ensure the reaction has run to completion.

Any remaining oxalic acid must now be destroyed. The theory behind this is discussed above in the section entitled 'Disadvantages and Dangers of the NaOH Pathway.' For this preparation, $NaHCO_3$ is added in approximately 5g increments followed by stirring until a reaction no longer takes place. Once this point is reached, one additional 5g increment is added followed by thorough stirring to make absolutely sure no oxalic acid remains.

The formed crystals are then left for 30 minutes to coalesce into a solid mass. After said time, the supernatant is decanted leaving behind only the crystals. These crystals are then scraped from the vessel and can be placed on trays in the sun or in a cool oven to dry, then crushed and stored for later use.

Strontium Carbonate ($SrCO_3$)

Strontium carbonate is a seldom utilised red colouring agent in pyrotechnic compositions, most often those containing potassium chlorate. The more common form of strontium in pyrotechnics is strontium nitrate, however, there is no over the counter source of this I am aware of. Strontium carbonate can be found in most large pottery supplies stores as a replacement for barium carbonate in pottery glazes. It generally costs $20-$100 USD per kilogram depending on the source and quantity purchased.

When strontium carbonate from the pottery store is used in chlorate-containing pyrotechnic compositions, it is first necessary to ensure it contains no sulphides. Sulphide presence in chlorate stars drastically increases their sensitivity which can lead to spontaneous or accidental ignition. This increased ignition risk is NOT insignificant. The risk which these combinations carry is ill-described as less than extreme.

To test for sulphide presence in a sample of strontium carbonate, a small amount is mixed with weak acetic acid to yield a gaseous emission. This liberated gas is subsequently inhaled, and the smell determines the presence of impurities. If the sample is pure carbonate only CO_2 is liberated, whereas, if sulphides are present H_2S gas is given off which is detectable by the tester as a strong rotten egg smell. CO_2 also has an odour, but this is not detectable in the amounts which it is produced in this test.

In more specific terms, this test is performed by placing one quarter of one gram of a strontium carbonate sample in a test tube and covering it in twenty times it's weight in 4%-6% acetic acid. Such a solution can be purchased at the grocery store as standard cooking vinegar. This is then left to react for twenty seconds. After this time has passed, the top of the test tube is brought three centimetres from the nose and, with wafting, the gasses being given off are carefully inhaled.

If no smell is detected, the sample is pure and can be used. If a detectable but minor smell is noticed, the sample is slightly impure. Experiment done by this author has shown that samples which test this way, when combined into compositions, do not detectably increase their sensitivity and can be used. If a strong easily recognisable rotten egg smell is produced, the sample is too contaminated to be used directly in pyrotechnics and should be discarded. Another sample from an alternative pottery store should be sourced and tested likewise. If a pure alternative sample cannot be sourced, impure samples can be purified via the method detailed below.

*IF A SAMPLE TESTS STRONGLY POSITIVE FOR SULPHIDES IT **MUST NOT** BE USED DIRECTLY!*

Chemical Purification of Sulphide Contaminated $SrCO_3$

Strontium carbonate can be purified with relative ease using two reactions. Firstly, a reaction with HCl to form aqueous strontium chloride, then a reaction of this strontium chloride with a soluble carbonate to reprecipitate pure strontium carbonate. In this procedure, any sulphides present are converted to chlorides and the sulphur is liberated as H_2S gas. As a result, when the carbonate is reprecipitated all of the sulphur is removed.

To begin this purification the sample of contaminated strontium carbonate must be reacted with a slight excess of 9.9M (31.45%) HCl from the hardware store. Sourcing of HCl is discussed on page. 37. This converts both the strontium carbonate and strontium sulphide present to highly soluble strontium chloride by the reaction shown below. In this reaction, all the strontium sulphide impurities are destroyed, and the sensitising sulphur atoms are removed from the sample as H_2S gas.

$$1.)\ SrCO_{3(s)} + 2HCl_{(aq)} \rightarrow SrCl_{2(aq)} + CO_{2\ (g)} + H_2O_{(l)}$$

$$2.)\ SrS_{(s)} + 2HCl_{(aq)} \rightarrow SrCl_{2(s)} + H_2S_{(g)}$$

The amount of HCl added at this stage is not critical; any excess will be destroyed in the subsequent step. It is, though, desirable to have a reasonable excess of HCl to make absolutely sure no sulphides remain. The liberation of CO_2 is a convenient indicator as to the completion of this reaction; HCl should be introduced until its addition no longer causes CO_2 to be given off. When this point is reached, an arbitrary excess should be added and the reaction left for ten minutes to run to completion.

To convert this sample of strontium chloride back to carbonate, it must be reacted with a solution of a soluble carbonate salt. This will reform the strontium carbonate and yield the chloride of the salt used which remains in solution.

Carbonates are generally insoluble, however, group one carbonates and ammonium carbonate are soluble and can be used.[†] The prohibitively high cost of Li^+, Rb^+ and Cs^+ salts, though, makes their use inappropriate. This leaves Na^+, K^+ and NH_4^+, although, sodium contamination is an ever-present issue for the pyrotechnic chemist and, thus, sodium salts should be avoided if possible. Because red is a comparatively forgiving colour, sodium carbonate can be used if the potassium or ammonium equivalents cannot be sourced. If this is done, additional washing steps must be employed to remove all Na^+ and performance may suffer.

[†] Table 4.1. Standard Ionic Solubility Chart. page. 39.

As well as carbonate salts, bicarbonate salts can be used for this reaction. In general, bicarbonate salts are harder to source, more expensive, and less convenient than their carbonate equivalents and as such are avoided. Contrary to this, however, ammonium bicarbonate tends to be far easier to acquire than ammonium carbonate and is, thus, the ideal ammonium salt to be used in this reaction. Ammonium bicarbonate can be sourced from organic food supplies stores where it is sold either under its chemical name or as 'Baker's Ammonia.'

Potassium carbonate sourcing is discussed above in the copper oxychloride section on page 15. Sodium carbonate has numerous sources, however, the best of these is as 'Washing Soda' from the grocery store which costs approximately $2 USD per kilogram.

The balanced chemical equations for all the carbonate reactions are laid out below along with tables for solubility of all relevant salts.

$$K_2CO_{3(aq)} + SrCl_{2(aq)} \rightarrow SrCO_{3(s)} + 2KCl_{(aq)}$$

$$2NH_4HCO_{3(aq)} + SrCl_{2(aq)} \rightarrow SrCO_{3(s)} + 2NH_4Cl_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$

$$Na_2CO_{3(aq)} + SrCl_{2(aq)} \rightarrow SrCO_{3(s)} + 2NaCl_{(aq)}$$

Table 4.17. Solubility Table for Strontium Chloride ($SrCl_2$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	46.93	49.10	52.51	57.26	66.47	72.24	83.28	88.01	91.17	94.93	99.48

Table 4.7. Solubility Table for Potassium Carbonate (K_2CO_3)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	107.04	109.64	113.22	117.39	121.73	127.27	133.64	140.38	147.52	156.41	107.04

Table 4.2. Solubility Table for Ammonium Bicarbonate (NH_4HCO_3)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	11.86	15.87	21.36	28.87	38.7	51.98	70.65	97.24	138.66	208.64	354.55

Table 4.12. Solubility Table for Sodium Carbonate ($NaCO_3$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	6.88	12.11	21.8	40.25	48.81	47.49	46.41	45.56	45.14	44.72	44.72

Simplified Purification

In the above section I have not specified the actual amounts of the various chemicals to be used and have simply left the calculations to the reader. To save the reader time in completing these calculations, I have below laid out an example purification of 100g of strontium carbonate in full. This purification can be scaled if desired.

Destruction of Sulphides

This destruction step, depending on the amount of sulphide present, and the batch size being processed, can liberate large amounts of toxic H_2S gas. This reaction must, therefore, be done outside and ideally away from people who may be adversely affected by the strong smell. Moderately high concentrations of H_2S gas – such as may build up indoors – paralyse the olfactory system and can be lethal.

Primary Addition

Into a heat resistant glass vessel is added 100g of contaminated strontium carbonate and 100ml of distilled water. This is followed by 150ml of 9.9M HCl introduced incrementally to prevent foam over from liberated CO_2. Once all the acid is added, the solution is stirred vigorously and left for ten minutes to allow all the $SrCl_2$ to dissolve and any remaining $SrCO_3$ to react.

Secondary Additions

After this ten-minute period has elapsed, if carbonate remains, additional HCl should be added in 10ml increments followed by stirring until no visible carbonate remains. If additional charges of HCl are required, the acid has deteriorated and reduced in concentration, however, this will not affect the chemistry in any way.

After completing these steps, a pure sample of strontium carbonate will yield a crystal-clear solution of strontium chloride, however, this is not to be expected. The solution created will be a dirty brown colour due to inert impurities which this purification cannot remove. These do not sensitise compositions and are of no concern.

Strontium Carbonate reprecipitation

Table 2.1. Carbonate Solution Information for 100g Strontium Carbonate Purification

Carbonate Salt	*Mass Required (Grams)*	*Water Required (25°C) (Millilitres)*	*Solution Concentration (Moles/Litre)*
Potassium Carbonate (K_2CO_3)	110g	150ml	5.30M
Ammonium Bicarbonate (NH_4HCO3)	130g	600ml	2.75M
Sodium Carbonate ($NaCO_3$)	85g	400ml	2.00M

Preparation of the Carbonate Solution

Into a glass vessel is added either 0.8M of potassium or sodium carbonate, or 1.6M of ammonium bicarbonate. This salt is followed by sufficient water to dissolve it. These molar amounts represent a 20% excess to account for the reaction between the carbonate and residual HCl.

If potassium carbonate is used, 110g of the salt and 150ml of water is required. If ammonium bicarbonate is used, 130g of the salt and 600ml of water is required. If sodium carbonate is used, 85g of the salt and 400ml of water is required. These values assume room temperature water is used.

Once the appropriate amount of carbonate salt and water is added to a glass vessel, the solution is stirred to dissolve all the salt. If not all the salt dissolves, additional water should be added until total dissolution occurs.

Precipitation and Separation

The carbonate solution created is then added to the strontium chloride in a large vessel to prevent foam over from liberated CO_2. Initially, all carbonate introduced will react with residual HCl. After all the HCl has been consumed, the carbonate will begin to react with the chloride precipitating strontium carbonate. This addition should be continued until the introduction of the carbonate solution no longer causes a liberation of CO_2 gas. Using excess carbonate solution is of no concern as it will be easily washed from the sample.

Once sufficient carbonate solution has been added, the suspension is left to stand overnight to settle the strontium carbonate. The supernatant is then decanted. The carbonate which remains on the bottom of the vessel will now be completely free of all sulphides. To separate it, a filtration followed by a washing with distilled water is employed.

Red Iron Oxide (Fe_2O_3)

Red iron oxide is used as an additive to various prime compositions and also as a component in some star compositions to give a very bright orange to red flame. Of course, iron oxide also finds use in the famous – maybe even infamous – thermite reaction.

Sources of iron oxide are numerous; however, the best source of iron oxide is the pottery supply store where it is sold for use in colouring of pottery. Pottery suppliers generally stock iron oxide in 1kg bags ranging from $3-$5 USD. An alternate source of Fe_2O_3 is the concrete section of the local hardware store where it can be found as an additive to turn concrete bright red. A number of syntheses for producing iron oxide also exist, although, compared to its purchase, these are almost always not economical, so will not covered here.

Appendix #1

Preparation Notes for the Helix Series Pyrotechnic Compositions

All of these compositions are to be primed with Helix Prime once dry, or, if preferenced, whilst wet.

A note on chemical purity: For the majority of compositions detailed in this guide, the chlorate made via the production process detailed in the sourcing and synthesis section above is sufficient to produce a vibrant and recognisable colour. However, for the preparation of Helix Blue, Helix Purple and Helix Pink, further purification of the chlorate used is necessary. This is because the agricultural KCl used to make this $KClO_3$ *contains a reasonably large amount of sodium. This ionic species is capable of washing out sensitive compositions. Removing this sodium requires a double recrystallisation. Details of this procedure have been included below in the section 'Recrystallisation of* $KClO_3$ *for Sensitive Star Compositions' which can be found on page. 36.*

Helix Red, Helix Orange, Helix Yellow and Helix Green

Preparation of small batches (≤200g)

1. In a coffee grinder, place all the components excluding the primary fuel/s and binding agent
2. Blade mill these components together for 30 seconds to 1 minute or until they appear air-float by visual inspection
3. Remove the milled components from the grinder and pass them through a 40-mesh screen. Anything that does not pass can be discarded

4. Place into the coffee grinder the binder and primary fuel/s
5. Blade mill these components together for 30 seconds to 1 minute or until they appear air-float by visual inspection
6. Remove the milled components from the grinder and pass them through a 40-mesh screen. Anything that does not pass can be discarded

7. Using a 40-mesh screen, combine together thoroughly the two powdered mixtures until homogenous

Dampen with a 75% water 25% alcohol solution

These compositions are best cut or pumped

Preparation of standard/ large batches (≥200g)

1. In a coffee grinder, blender or ball mill, reduce each of the components down separately to pass a 100-mesh screen
2. Using a 40-mesh screen, combine together thoroughly the finely powdered chemicals until homogenous.

Dampen with a 75% water 25% alcohol solution

These compositions are best cut or pumped

Helix Blue, Helix Purple and Helix Pink

Preparation of small batches (≤200g)

1. In a coffee grinder, place all the components excluding the lactose, dextrin and uPVC cement
2. Blade mill these components together for 30 seconds to 1 minute or until they appear air-float by visual inspection
3. Remove the milled components from the grinder and pass them through a 40-mesh screen. Anything that does not pass can be discarded

4. Using a 40-mesh screen, integrate into this mixture the lactose powder and dextrin until homogenous
5. Place this mixture into either a small metal container, a glass beaker or a paper cup. The first of these is most appropriate. If plastic is used, the uPVC cement will melt through it
6. In a separate non-plastic container, weigh out the appropriate amount of uPVC cement
7. Pour this uPVC cement into the powdered mixture and using a wooden popsicle or other non-plastic implement mix it into the composition thoroughly
8. Weigh out 3% of the weight of the composition in distilled water
9. Add this water to the existing mixture and integrate it thoroughly

10. Using the implement from step seven, remove the composition from the vessel it has been mixed in and place it onto a sheet of baking paper
11. Form the composition into a patty of the appropriate thickness
12. Leave this patty in a safe location for one to two hours to allow the majority of the solvents to evaporate. This will harden it enough to be cut into stars
13. Once the patty has dried enough it no longer sticks to itself when sliced, it can be cut into cubes of the appropriate size

*These compositions **must** be cut*

A cautionary note: These compositions contain a large amount of MEK which is a highly flammable organic solvent. Do not dry these compositions inside a home or in any place where the MEK may find an ignition source. Especially during the first one to two hour drying period, the vapours being released are very noticeable and pose significant risk. Once this first two hour period has passed and the stars are cut, the risk is greatly reduced. Even so, until they are totally dry, I advise proceeding with great caution.

Preparation of standard/ large batches (≥200g)

1. In a coffee grinder, blender or ball mill, reduce each of the components – excluding the uPVC cement – down separately to pass a 100-mesh screen
2. Using a 40-mesh screen, combine together these finely milled components – excluding the uPVC cement

3. Place this mixture into either a small metal container, a glass beaker or a paper cup. The first of these is most appropriate. If plastic is used, the uPVC cement will melt through it
4. In a separate non-plastic container, weigh out the appropriate amount of uPVC cement
5. Pour this uPVC cement into the powdered mixture and using a wooden popsicle or other non-plastic implement mix it into the composition thoroughly
6. Weigh out 3% of the weight of the composition in distilled water
7. Add this water to the existing mixture and integrate it thoroughly

8. Using the implement from step five, remove the composition from the vessel it has been mixed in and place it onto a sheet of baking paper
9. Form the composition into a patty of the appropriate thickness
10. Leave this patty in a safe location for one to two hours to allow the majority of the solvents to evaporate. This will harden it enough to be cut into stars
11. Once the patty has dried enough it no longer sticks to itself when sliced, it can be cut into cubes of the appropriate size

*These compositions **must** be cut*

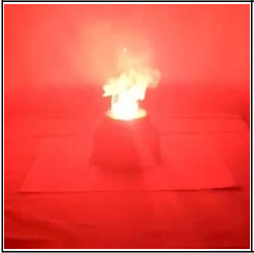
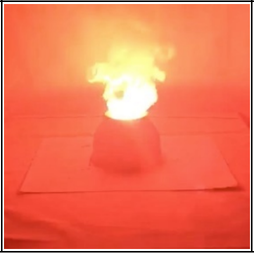
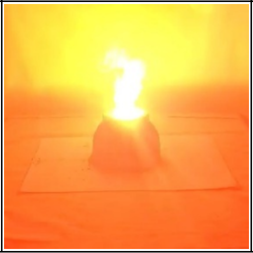
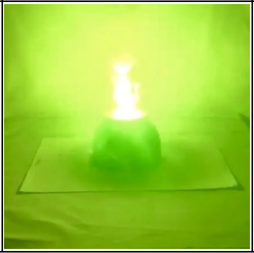
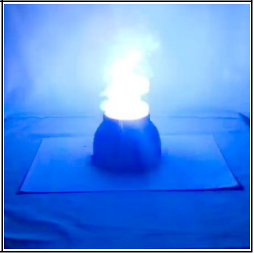
A cautionary note: These compositions contain a large amount of MEK which is a highly flammable organic solvent. Do not dry these compositions inside a home or in any place where the MEK may find an ignition source. Especially during the first one to two hour drying period, the vapours being released are very noticeable and pose significant risk. Once this first two hour period has passed and the stars are cut, the risk is greatly reduced. Even so, until they are totally dry, I advise proceeding with great caution.

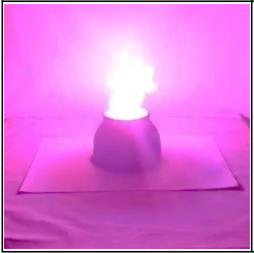
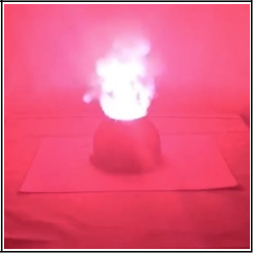
Helix Black Powder Prime

1. Ball mill together the potassium nitrate, sulphur and charcoal for 1-2 hours
2. Using a 40-mesh screen, integrate in the dextrin, spherical aluminium powder and red iron oxide until homogenous

Colour Testing of the Helix Series Compositions

Table 3.1. Helix Series Colour Tests

Helix Red	Helix Orange	Helix Yellow	Helix Green	Helix Blue
				

Helix Purple	Helix Pink
	

This table is included only as a rough guide and colour stars tend to look different when burning at distance. It does, however, give a demonstration of the performance of the Helix Star Compositions

All tests were photographed from approximately 1.5m using stars that were cut and primed to ¼"

Composition Performance Notes for the Helix Series Compositions

Helix Red

Gives a reddish orange colour up close which appears a deeper red at distance. This composition is not as deep as strontium-nitrate-based reds but is still very acceptable.

Helix Orange

Gives an unmistakable and beautiful orange both up close and at distance. The use of shellac is to keep the colour pure orange, without it, the colour appears simply a low-quality red.

Helix Yellow

Gives a deep yellow at distance, however, up close, looks somewhat orange. The sodium oxalate used in this composition does not give a perfect yellow emission, however, the colour is close enough to be acceptable.

Helix Green

Gives an unmistakable green both up close and at distance. When viewed in close proximity, the colour can appear a touch yellow, however, when viewed in the sky, this is replaced by a deep, vibrant and unmistakable green.

Helix Blue

Gives a very good deep royal blue. Appears washed out at close range, but at distance the colour is far better. Oxygen balance is negative, so the star must be traveling through the air at speed to give the desired colour. Without the addition of PVC, a weak violet colour is produced.

Various chemicals in this formula can be substituted. The formula given here, however, yields the truest blue in my opinion. There are, however, noted advantages to various substitutions and I have thus compiled below a series of substitutions which I have successfully performed. These include the substitution of: copper oxychloride for copper oxide, pure copper oxychloride for a copper oxychloride fungicide, PVC cement for PVC resin powder and lactose for various other fuels.

Helix Purple

Gives a rich magenta/ purple sitting closer to the purple end of the spectrum. There is some academic debate surrounding what colour a purple fireworks star should be. This is mainly because there is such a wide range of ‘purple’ colours as purple is not a true spectral colour. The composition given here is tuned to my personal taste, however, if a deeper colour is desired the formula can be tuned accordingly. This composition contains 10% colouring agent by weight. Of that 10%, the combination of blue to red colouring agents is done in an 80:20 ratio (Blue : Red). An adjustment to 85:15 yields a brighter purple violet colour, and an adjustment to 90:10 gives a deeper purple blue colour. Conversely, an adjustment to 75:25 gives a magenta, an adjustment to 70:30 yields a very pinkish purple, and an adjustment to 45:55 gives a vibrant pink. This final ratio is used to create Helix Pink.

Helix Pink

Gives a hot pink both up close and at distance. The colour is instantly recognisable and extremely vibrant. Emission purity is notably enhanced by the addition of PVC, without it, the colour appears only a weak red.

Substitutions for Helix Blue, Helix Purple and Helix Pink

The substitutions given here have been prefaced in the composition note sections for Helix Blue, however, they can likewise be performed on Helix Purple and Helix Pink.

Substitution of Copper Oxychloride for Copper Oxide

Whether to avoid a complex and timely synthesis, because of inaccess to the reagent chemicals, or for means of simplicity, the reader may want to replace the copper oxychloride in these formulas with copper (II) oxide. The ratio for this substitution is 1:1. The colour yielded is noticeably less deep which makes the star look somewhat washed out even at distance. Regardless of this, the colour is still recognisably blue. Copper oxide is sold at almost all pottery stores as a colourant for ceramics ranging from $10-$50 USD per kilogram.

Copper oxide contains 80% copper and 0% chlorine by weight, whereas copper oxychloride contains 60% copper and 15% chlorine by weight. Because of these differences, a 1:1 substitution gives slightly less than ideal atomic flame species, however, the difference is likely small enough not to matter. I theorise, although I have not tried this, that a substitution of 0.75:1 ($CuO : Cu_2(OH)_3Cl$) with the remaining 25% split between PVC and potassium chlorate may give slightly better results. PVC acts as a fuel as well as a chlorine donor, hence the additional chlorate. The above is truthfully provided only in speculation; however, it may be of assistance to someone aiming to get a deep blue without the use of copper oxychloride.

Substitution of Copper Oxychloride for Copper Oxychloride Fungicide

Various copper compounds are available over the counter; however, copper oxychloride fungicide is unique. Copper oxychloride is different because it can be used directly in compositions without any purification or processing. Copper oxide from the pottery store can also be used in this way, but it gives a far less impressive colour.

In Australia, copper oxychloride fungicide is sold in most small hardware stores and gardening centres, however, it is not sold in any major hardware chains at the time of writing. Why this is, I do not know, although, I assume it has something to do with the regulation regarding copper oxychloride.

Many states have extremely strict regulation regarding the use of copper oxychloride as it is a particularly problematic environmental toxin. This, I think, is why it is so difficult to find in national hardware chains. As far as I can tell, copper oxychloride fungicide is in fact not available for sale in the USA because of these environmental concerns

When attempting to locate a source of copper oxychloride, calling up various local hardware stores is the best route to take. They should be able to inform if it is something they stock and how much it will cost. Copper oxychloride from this source is approximately $40-$50 USD per kilogram.

The MSDS sheets for copper oxychloride fungicides are unusually unhelpful in determining the amount of actual copper oxychloride contained in the product and tend only to provide one value: ‘Copper as copper oxychloride – 500g/kg.’ The table over the page is from an MSDS sheet of a brand of copper oxychloride fungicide I have tested with.

Components	CAS No.	Conc, %	TWA (mg/m^3)	STEL (mg/m^3)
Copper as copper oxychloride	1332-40-7	500g/kg	not set	not set
Other nonhazardous ingredients	-	to 100%	not set	not set

Using values for this table and simple chemistry it is possible to calculate the purity of this copper oxychloride fungicide. It is worth noting here, in case it is not clear, that the value 500g/kg denotes that the product contains 50% w/w of metallic copper in its oxychloride form.

The following calculation is based on a theoretical 100g sample of copper oxychloride fungicide which, because of the values given in the MSDS, is known to contain 50g of metallic copper.

$$Sample \rightarrow 100g\ of\ Copper\ Oxychloride\ Fungicide$$

$$Sample\ contains\ 50g\ of\ metallic\ copper\ (Known\ from\ MSDS)$$

$$\frac{Mass}{Molar\ mass} = Moles$$

$$\frac{50}{63.55} = 0.7868\ (Moles\ of\ Metallic\ Copper\ Present)$$

Two moles of metallic copper are present in one mole of copper oxychloride, therefore, the moles of copper oxychloride present will be half that of the metallic copper.

$$\frac{0.7868}{2} = 0.3934\ (Moles\ of\ Copper\ Oxychloride\ Present)$$

$$Moles\ \times Molar\ Mass = Mass$$

$$0.3934\ \times 213.56 = 84.0145\ (Mass\ of\ Copper\ Oxychloride\ Present)$$

This calculation shows that this theoretical 100g sample of copper oxychloride fungicide contains almost exactly 84g of pure copper oxychloride. From this, the following deductions can also be made.

$$100\% - 84.0145\% = 15.9855\%\ (Percentage\ of\ Impurity\ Present)$$

$$\therefore Purity\ \approx 84\%$$

$$\therefore Impurity \approx 16\%$$

$$\therefore Theoretical\ Adjustment\ Factor\ (1 + Ratio\ of\ contaminate\ to\ product) \approx 1.19\ (+19\%)$$

When using copper oxychloride fungicide in compositions there are two key differences in performance, which I will cover here. Firstly, the use of the fungicide results in the development of a substantially thicker slag layer around the burning star. This is due to the impurities present in the fungicide, however, it is unclear exactly what phenomenon is causing this effect. It is possible this reduces the star's access to atmospheric oxygen, though, testing has shown this is not the case and thus this slag is of no concern.

Secondly, the use of oxychloride fungicide in the amount specified for pure oxychloride results in a very slight reduction in colour depth giving a slightly lighter blue. This is because less actual oxychloride is added. The term 'washed out' has been purposely withheld as it does not accurately describe this effect. Simply, the colour becomes lighter, not any less blue. To combat this, the oxychloride fungicide can be substituted in a ratio of 1.2:1 (Oxychloride Fungicide : Pure Oxychloride) which ensures the correct amount of copper and chlorine are present during combustion. This adjustment does not, however, produce a markedly better colour and slows the burn rate of the star. Consequentially, the adjustment is not recommended, and the substitution is best done 1:1.

Substitution of PVC Cement for PVC Dry Blend Resin Powder

Chlorine donors are an invaluable tool of the pyrotechnician and facilitate the economical and safe production of colours which would otherwise be unattainable. In this star system, PVC cement is used as a chlorine donor because of its universal availability, however, it is not without its drawbacks. Chief among these is the mess and inconvenience of working with PVC cement compositions. For example, their inability to be pumped or rolled.

Considering these difficulties, I present the reader with two alternative options. Firstly, in breaking with the premise of this entire publication, I bring to the reader's attention the potential of having PVC powder shipped to them from a dedicated pyrotechnic supplier such as those which operate out of the USA. PVC powder is an inert and non-controlled substance and, because it is used in relatively small amounts, it is economically feasible to purchase internationally – even at great expense. For example, 500g of PVC powder could make over 7kg of stars. For a small workshop, this is a decent batch.

Although not exorbitantly expensive when used wisely, PVC powder sourced internationally is still not by any means 'cheap.' Further, it completely breaks the ideals of OTC pyrotechnics. Considering these things, the second option presented is PVC dry blend resin powder.

Across the world, many companies specialise in the production of onsite PVC injection moulded parts for high-speed prototyping. Although these companies only generally work with what are called 'PVC Blends,' which are a combination of pure PVC powder along with plasticising agents, colourants and fillers, the companies that supply them these 'blends' have access to pure PVC powder. In industry, this is known as 'PVC Dry Blend' and is packed in large 25kg (55lb) sacks for distribution to industrial companies. Finding one of these PVC dry blend suppliers is the ideal sourcing for pyrotechnics grade PVC.

A google search for "PVC Resin Manufacturers [City]," "PVC Dry Blend [City]" or "PVC Resin Suppliers [City]" should be able to locate one of these suppliers within close proximity to the city entered. In most cases, informing a company you'd be willing to come and pick up the product is enough to get them to sell you a single bag of resin. It is important to know industry terminology, so do a bit of reading on the Wikipedia page for PVC as well as some industry websites. The main information required is that you are looking for PVC dry blend with no plasticisers or additives, although, knowing additional information does no harm.

A couple of other important distinctions the reader may come across. They may ask if 'Rigid' or 'Flexible' PVC dry blend is required. The flexible PVC has plasticisers so purchase the rigid type. They may also ask if you want 'Emulsion Grade' or 'Suspension Grade' PVC. Chemically, these two products are identical, however, they are not the same. The physical conditions in the reaction vessel which produced the polymers were different and thus produce differently sized particles of PVC. Emulsion grade PVC is the finer of the two powders and, thus, is desired if available. However, I have never been personally able to find it and just mill the suspension grade PVC down to a fine powder.

Depending on the whims of the company, the cost of a 25kg (55lb) bag of PVC can vary wildly. However, in my personal experience, a bag costs around $90 USD. Although, I know others who have been able to acquire a bag for free simply because they knew someone in the industry.

PVC Dry Blend Bag

Suspension Grade PVC

Given below are several established formulas which use almost the same chemicals as Helix Blue, however, receive their chlorine from more traditional powdered PVC. The formula from Hardt's performs adequately, however, it has been tuned for commercial use and consequentially values economics over colour purity.

The 50AE formulas are designed for amateur use and are tuned for performance only, thus, they are noticeably superior. There is, though, a need to exercise caution when dealing with the Sulphur Blue formula due to the well-established instability issues of chlorate sulphur mixtures. For the 'green' pyrotechnician, this composition is not advised, although, for completeness, it has been included here.

50AE himself also gives brief comments on these formulas in a short Passfire entry from 2011 which is paraphrased below. Having tested all three formulas myself, I can verify 50AE's descriptions. His personal preference is for the somewhat brighter blue shellac offers, whereas I prefer the deep rich colour of very low temperature lactose stars. The reader is encouraged to experiment and determine which composition is best suited to their taste.

> *"My favourite is the Shellac Blue. It is bright and very nice for my taste. The Lactose Blue is deep but dim. The Sulphur Blue is between both with a slight violet tint."* [1]

As a final note, it is also worth stating that this PVC powder substitution should not be perform with the Helix compositions as they are tuned for use with the cement. Instead, one of the below formulas should be used. Assuming the PVC powder is sourced and milled correctly, colour quality and performance will be equal or better than that of the Helix compositions. Finally, to achieve pink, purple and magenta stars, the ratios on page. 31. under the section 'Helix Purple' should be employed.

50AE Lactose Blue [1]

Potassium Chlorate (66 Parts)

Copper Oxychloride (13 Parts)

Lactose (14 Parts)

Powdered PVC (7 Parts)

Dextrin (5 Parts)

50AE Shellac Blue [1]

Potassium Chlorate (67 Parts)

Copper Oxychloride (13 Parts)

Shellac (5 Parts)

Powdered PVC (8 Parts)

Dextrin (5 Parts)

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[1] 50ActionExpress [50AE], TOPIC: 'Is dextrin the reason why my blue color is washed ?', *PASSFIRE.COM* (14th February 2011 07:27 AM) Post #19 <Forum » Fireworks! » Shells>.

50AE Sulphur Blue [1]

Potassium Chlorate (68 Parts)

Copper Oxychloride (13 Parts)

Sulphur (13 Parts)

Powdered PVC (8 Parts)

Dextrin (4 Parts)

Hardt Blue #2 [2]

Potassium Chlorate (65 Parts)

Copper Oxychloride (16 Parts)

Lactose (10 Parts)

Powdered PVC (5 Parts)

Dextrin (4 Parts)

Recrystallisation of $KClO_3$ for Sensitive Star Compositions

Although, majoritively, potassium chlorate produced using agricultural KCl is sufficiently free of sodium contamination to yield high quality coloured stars, in some cases, the small amount of sodium that is present is enough to disrupt or destroy the colour being emitted. Blue fireworks stars suffer particularly from this phenomenon; however, purples and pinks are likewise susceptible. Other colours will also be washed out if enough sodium is present, but the amount required for this to occur tends to be much more. In respect to this guide, the compositions which require recrystalised chlorate are Helix Blue and Helix Purple and Helix Pink. When producing these compositions, it is advised that the potassium chlorate being used has undergone at least one recrystallisation. When making pink stars, a single recrystallisation is sufficient, however, when making blue and purple stars two recrystallisations are strongly recommended. This short section sets out a simple procedure for performing a recrystallisation of potassium chlorate. This section assumes a basic knowledge of the use of solubility curves and standard recrystallisation procedure.

The major form of sodium present in the potassium chlorate produced from agricultural potassium chloride is sodium chloride which is the form of sodium this section discusses the removal of

This recrystallisation can be performed at various volumes, however, due to the slower cooling of larger bodies of water, a reasonable scale is desired. Personally, I perform my recrystallisations using 1.5L of distilled water and 600g of impure potassium chlorate. This size works well to provide a good rate of cooling whilst not being too large to be unmanageable.

As can be seen in the tables provided over the page (4.8) (4.13), the solubility of both sodium chloride and potassium chlorate at 100°C (212°F) is quite high, however, as the temperature drops, the solubility of potassium chlorate falls sharply to a solubility of only 3.12g/100ml at 0°C (32°F). Conversely, the solubility of sodium chloride stays extremely stable. This is the property which will be exploited in this recrystallisation.

It is unwise to attempt to recrystalise from a totally saturated solution of potassium chlorate, instead, adding enough chlorate to saturate the solution at between 80°C and 90°C is ideal. When I perform this recrystallisation I use 40g/100ml of water which gives a manageable solution that forms large crystals. Increasing the concentration of potassium chlorate much above this point produces a large amount of small relatively impure crystals that form soon after the beginning of the recrystallisation. Although purer than the starting crystal crop, these still contain a large amount of sodium chloride and are unacceptable.

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[2] Alexander Hardt, *Pyrotechnics* (Pyrotechnica Publications, 2001) Ch. 15, Pg. 148, Table 15-10 Blue Stars. (1).

Table 4.8. Solubility Table for Potassium Chlorate ($KClO_3$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	3.12	4.90	7.23	10.14	13.71	18.01	23.26	29.28	36.76	46.05	57.85

Table 4.13. Solubility Table for Sodium Chloride (NaCl)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	35.65	35.72	35.89	36.09	36.37	36.69	37.04	37.46	37.93	38.47	38.99

To increase the purity of the final product, it is possible to insulate the solution as it cools, thus, forming larger crystals. I have, however, found this to be unnecessary. It does no doubt increase the purity of the crystal crop attained, but this improvement is not noticeable in the stars produced with the chlorate. Simply leaving the cooling solution in a reasonably warm place gives adequately slow cooling to yield acceptable results.

I will not go into the process of recrystallisation here because I take it as assumed knowledge, but I will briefly state that there is no deviation from the general procedure that has not been covered here. Simply researching and following a general guide for recrystallisation will be sufficient.

Additional Chemical Sourcing Information

Hydrochloric Acid Sourcing (HCl)

Hydrochloric acid is an extremely important pyrotechnic chemical reagent which finds use in a number of syntheses. HCl is a quite common industrial chemical so can be found in a number of products, however, the best HCl for pyrotechnic applications can be found in the concrete or pool care section of the hardware store. It is sold in these sections for concrete cleaning and pool pH adjusting respectively. When purchasing HCl from the concrete section it tends to be labelled simply as ‘Hydrochloric Acid,’ however, when purchasing it from the pool care section it will often be labelled as either ‘Muriatic acid’ or ‘Pool Acid.’ All three of these, however, are chemically identical. HCl from the hardware store has a concentration of approximately 9.9M (31.45%), although, this will decrease with age. The cost of HCl from this source tends to be $1-$5 USD per litre.

Boric Acid Synthesis (H_3BO_3)

Boric acid is a weak acid added to select pyrotechnic compositions to prevent a reaction between nitrate compounds and fine metallic powders. This reaction can occur when a nitrate such as potassium nitrate is present in a composition with an easily reduced metal such as aluminium or magnesium. This reduction occurs to a greater degree when the composition also contains a basic salt such as sodium bicarbonate or sodium oxalate.

Various schools of thought exist regarding when boric acid should be used in compositions. It is the opinion of this author that, when working in small batch sizes and with spherical aluminium, the addition of boric acid is not generally necessary. When working in small quantities, any heat created by the reaction quickly dissipates from the batch preventing a run-away reaction. In addition, when using spherical aluminium, the actual exposed surface area available to react is relatively small meaning any possible reaction occurs quite slowly. Contrary to this, when working with large batches or with flake/ flitter aluminium, the addition of boric acid is advised. In terms of these mixtures, a large batch is considered 5kg (11lb) or more. In saying this, I do not mean to downplay the dangers that exist here, simply to acknowledge that the risk is reasonably managed at the amateur level without boric acid. If the reader intents to manufacture large batches of stars or would appreciate the increased safety that comes with the addition of boric acid, a synthesis is laid out below.

Boric acid is prepared with relative ease by the reaction of a sodium tetraborate decahydrate solution with a concentrated strong acid. Most commonly, this is done using nitric acid, however, in the amateur laboratory, HCl finds more common use. Sodium tetraborate can be purchased as borax at most hardware and grocery stores as a general-purpose cleaner and insect poison. HCl sourcing notes are given on page. 37.

To perform this synthesis, a solution of 0.5M sodium tetraborate prepared using boiling water is reacted with a stochiometric concentration of 9.9M (31.45%) hydrochloric acid. Upon addition of the solutions, a white precipitate is progressively formed which settles from solution, this precipitate is the boric acid. The reaction which takes place is given below.

$$Na_2B_4O_7 \cdot 10H_2O + 2HCl \rightarrow 4H_3BO_3 + 2NaCl + 5H_2O$$

This is a very simple preparation and few notes need to be made, however, I will make mention of two. Firstly, when preparing the solution of sodium tetraborate it should not be expected to clear completely. If kept heated for some time it will clear, however, it is best used shortly after preparation to prevent precipitation of the salt as the solution inevitably cools. Secondly, when separating the crystals, it is best to allow them to stand at the bottom of the reaction vessel for twelve hours before removal. After such time, the crystals will settle and lock themselves together forming a solid mass. The water can then be poured off leaving the crystals behind. These can then be lifted from the bottom of the vessel and dried in the sun or in a low temperature oven. To increase recovery, the solution can be chilled to just above freezing, however, this is not strictly necessary.

For those not well versed in chemistry the following may be of assistance. To produce 100g of boric acid, 154g of borax is dissolved in 800ml of boiling water. To this solution is added 82ml of 9.9M (31.45%) HCl followed by stirring. The crystals are separated as described above. This procedure can be scaled to the readers desire.

Appendix #2

Table 4.1. Standard Ionic Solubility Chart [v]

The following table is a reproduction of a standard inorganic solubility table such as can be found in any chemistry textbook. Contained are the rules for solubility of most commonly encountered ionic compounds with regard for alkali and transition metals. Exceptions to this table exist and compounds formed with exotic cations are not necessarily accounted for.

Ionic Species	Solubility in Water
Group 1 Compounds [Alkali Metals and H^+]	All Soluble
Ammonium Compounds (NH_4^+)	All Soluble
Nitrates (NO_3^-)	All Soluble
Acetates [Ethanoates] (CH_3COO^-)	All Soluble
Bicarbonates [Hydrogen Carbonates] (HCO_3^-)	All Soluble
Chlorides (Cl^-), Bromides (Br^-) and Iodides (I^-)	Soluble except Ag^+ and Pb^{2+}
Sulphates (SO_4^{2-})	Soluble except Ag^+, Pb^{2+}, Ba^{2+}, Sr^{2+} and Ca^{2+}
Carbonates (CO_3^{2-})	Insoluble except Group 1 and NH_4^+
Sulphites (SO_3^{2-})	Insoluble except Group 1 and NH_4^+
Phosphates (PO_4^{3-})	Insoluble except Group 1 and NH_4^+
Hydroxides (OH^-)	Insoluble except Group 1, NH_4^+, Ba^{2+}, Sr^{2+} and Ca^{2+}
Oxides (O^{2-})	Insoluble except Group 1, NH_4^+, Ba^{2+}, Sr^{2+} and Ca^{2+}
Sulphides (S^{2-})	Insoluble except Group 1, Group 2 and NH_4^+

Pyrotechnic Chemistry Solubility Tables [v]

Often in pyrotechnic chemistry the necessity arises to know the solubility of a specific compound over a range of temperatures. Searching for these values can be a tedious task, so for reader reference I have provided the solubility tables for all the chemicals used in the syntheses in this guide. Values in these tables are given in terms of grams of solute per 100ml of distilled water.

Table 4.2. Solubility Table for Ammonium Bicarbonate (NH_4HCO_3)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	11.86	15.87	21.36	28.87	38.7	51.98	70.65	97.24	138.66	208.64	354.55

Table 4.3. Solubility Table for Barium Chlorate ($Ba(ClO_3)_2$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	20.33	26.95	30.99	41.70	49.61	57.95	66.81	75.56	84.84	94.93	104.79

Table 4.4. Solubility Table for Barium Chloride ($BaCl_2$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	30.38	33.12	35.74	38.31	40.85	43.41	46.05	48.83	51.84	55.13	58.86

Table 4.5. Solubility Table for Boric Acid (H_3BO_3)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	2.68	3.70	5.01	6.69	8.81	11.48	14.81	18.91	23.92	30.04	37.55

Table 4.6. Solubility Table for Cupric Chloride ($CuCl_2$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	68.92	71.53	74.22	77.62	81.16	85.19	89.39	94.17	99.60	105.34	111.42

Table 4.7. Solubility Table for Potassium Carbonate (K_2CO_3)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	107.04	109.64	113.22	117.39	121.73	127.27	133.64	140.38	147.52	156.41	107.04

Table 4.8. Solubility Table for Potassium Chlorate ($KClO_3$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	3.12	4.90	7.23	10.14	13.71	18.01	23.26	29.28	36.76	46.05	57.85

Table 4.9. Solubility Table for Potassium Chloride (KCl)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	27.78	30.91	34.03	37.06	40.04	42.94	45.77	48.50	51.19	53.82	56.37

Table 4.10. Solubility Table for Potassium Hydroxide (KOH)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	94.93	103.25	113.68	127.79	137.53	141.55	146.91	153.81	161.78	171.00	182.49

Table 4.11. Solubility Table for Sodium Bicarbonate ($NaHCO_3$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	6.93	8.21	9.57	11.00	12.52	14.16	15.87	17.67	19.57	21.55	23.61

Table 4.12. Solubility Table for Sodium Carbonate ($NaCO_3$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	6.88	12.11	21.8	40.25	48.81	47.49	46.41	45.56	45.14	44.72	44.72

Table 4.13. Solubility Table for Sodium Chloride ($NaCl$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	35.65	35.72	35.89	36.09	36.37	36.69	37.04	37.46	37.93	38.47	38.99

Table 4.14. Solubility Table for Sodium Hydroxide ($NaOH$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	42.86	63.93	85.19	112.77	138.10	170.27	203.03	244.83	284.62	316.67	376.19

Table 4.15. Solubility Table for Sodium Oxalate ($Na_2C_2O_4$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	2.69	3.04	3.41	3.79	4.17	4.56	4.94	4.23	5.72	6.10	6.47

Table 4.16. Solubility Table for Sodium Tetraborate Decahydrate ($Na_2B_4O_7{\cdot}10H_2O$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	1.25	1.74	2.56	3.97	6.41	10.74	17.51	20.63	23.61	30.72	38.89

Table 4.17. Solubility Table for Strontium Chloride ($SrCl_2$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	46.93	49.10	52.51	57.26	66.47	72.24	83.28	88.01	91.17	94.93	99.48

Table 4.18. Solubility Table for Oxalic Acid Dihydrate ($C_2H_2O_4{\cdot}H_2O$)

Temperature (°C)	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
Solubility (g/100ml)	3.76	5.52	8.11	11.92	17.52	25.75	37.84	55.62	81.74	120.12	176.53

REPRODUCED FOR EASE OF NAVIGATION

Table 1.1. Helix Series Coloured Pyrotechnic Star Compositions

	Helix Red[i]	Helix Orange[ii]	Helix Yellow[iii]	Helix Green[iv]	Helix Blue	Helix Purple	Helix Pink	Helix Prime
Potassium Chlorate	70	76	76	28	48	48	48	-
Potassium Nitrate	-	-	-	-	-	-	-	75
Barium Chlorate	-	-	-	53	-	-	-	-
Copper Oxychloride	-	-	-	-	10	8	4.5	-
Strontium Carbonate	15	4	-	-	-	2	5.5	-
Sodium Oxalate	-	4	10	-	-	-	-	-
Colophony	10	8	9	10	-	-	-	-
Lactose	-	-	-	-	10.5	10.5	10.5	-
Horticultural Charcoal	1	-	-	5	-	-	-	15
Shellac	-	4	-	-	-	-	-	-
Clear uPVC Cement	-	-	-	-	28.5	28.5	28.5	-
Sulphur	-	-	-	-	-	-	-	10
-200# Aluminium	-	-	-	-	-	-	-	+5
Dextrin	4	4	5	4	3	3	3	+5
Red Iron Oxide	-	-	-	-	-	-	-	+5

A number of the compositions given here are adaptations of formulas from Hardt's 'Pyrotechnics' and Lancaster's 'Fireworks Principals and Practice.' References to the original formulas are provided as endnotes on the final page (page. 43)

References

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[i] Ronald Lancaster, *Fireworks Principals and Practice* (Chemical Publishing Co., Inc., 3rd ed, 1998) Ch. 10, Pg. 201, Red Roman Candle Star.

[ii] Alexander Hardt, *Pyrotechnics* (Pyrotechnica Publications, 2001) Ch. 15, Pg. 156, Table 15-14 Orange Stars. (1).

[iii] Alexander Hardt, *Pyrotechnics* (Pyrotechnica Publications, 2001) Ch. 15, Pg. 152, Table 15-12 Yellow Stars. (1).

[iv] Ronald Lancaster, *Fireworks Principals and Practice* (Chemical Publishing Co., Inc., 3rd ed, 1998) Ch. 10, Pg. 201, Green Roman Candle Star.

[v] W M Haynes, David R Lide and Thomas J Bruno (eds), *CRC Handbook of Chemistry and Physics* (CRC Press, 97th ed, 2016).

Further Reading

Fireworks Principals and Practice, Rev. Ronald Lancaster, (Chemical Publishing Co., Inc., 3rd ed, 1998)
Pyrotechnics, Alexander P. Hardt (Pyrotechnica Publications, 2001)
Fireworks Art the Science and the Technique [F.A.S.T], Takeo Shimizu, (Pyrotechnica Publications, 3rd ed, 1981)
Pyrotechnics, George W. Weingart (Chemical Publishing Co., Inc., 2nd ed, 1947)